

Naval Postgraduate School
Monterey, California 93943-5138

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SUMMARY OF RESEARCH 2000



Department of Meteorology

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Monterey, CA 93943-5000

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

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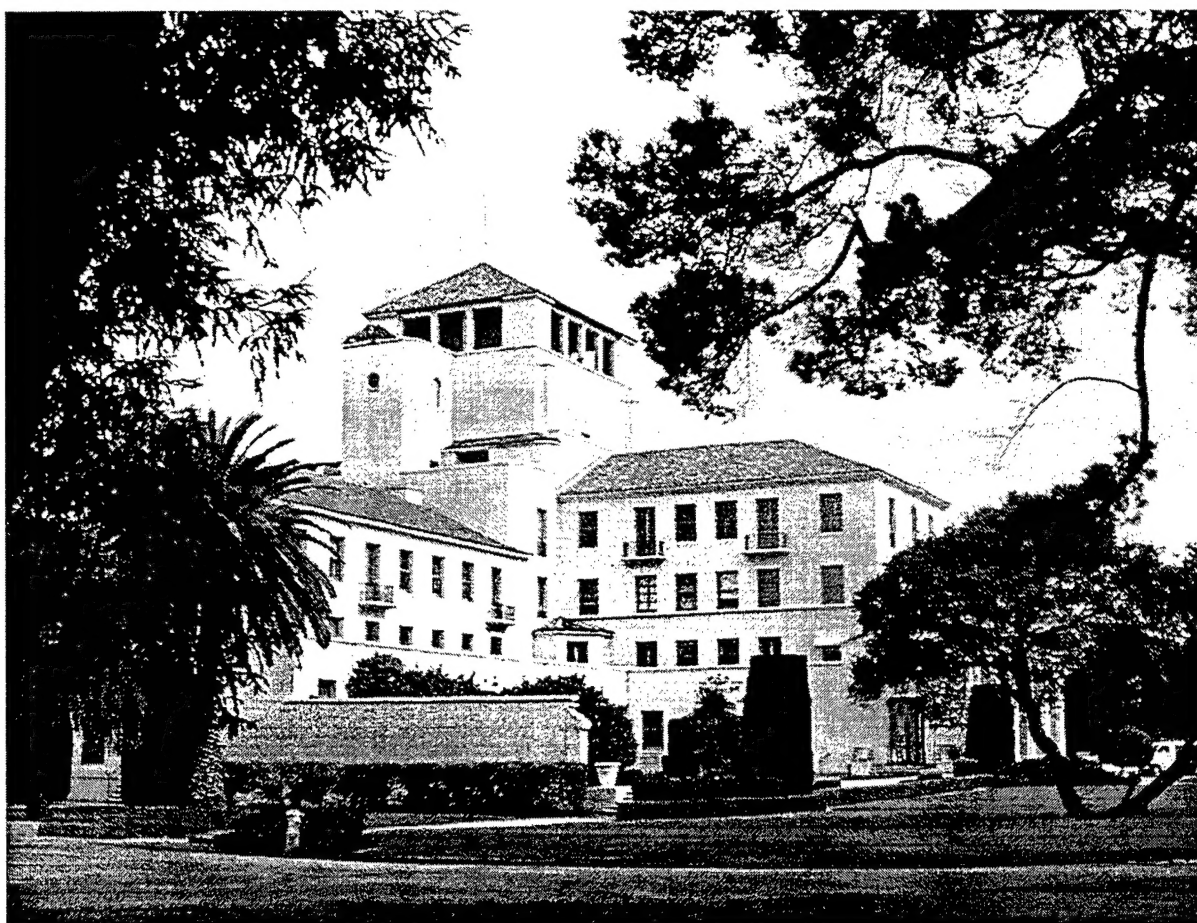


TABLE OF CONTENTS

Preface	xi
Introduction	xiii
Department Summary	3
Faculty Listing	5
Project Summaries	7
Monsoon Disturbances over the China Seas	7
East Asian Monsoon and Tropospheric Biennial Oscillations	8
Development of an Expert System Based on the Systematic Approach to Tropical Cyclone Track Forecasting	9
Application of the Systematic Approach to Tropical Cyclone Track Forecasting in the Western North Pacific and Extension to Other Tropical Cyclone Regions	10
Evaluation of TDROP for use in the Marine Atmospheric Boundary Layer	11
METOC Data Acquisition (MORIAH)	12
Operational METOC Measurement Systems (METCAST)	13
Buoy Measurement of Atmospheric Surface-Layer Mean and Turbulent/Flux Parameters and Surface Waves: Support of ICON and MUSE/AOSN	13
Near-Surface Scalar Profiles in Wallops '00: Flux-Buoy Measurements, Analyses, and Physical Modeling	14
Atmospheric CIMREP (Advanced Propagation Model)	14
Scaling Near-Surface Atmosphere and Wave Influences on Rf/EO Propagation over the Sea	15
Development and Validation of Multiple-Satellite Data Sets for Global Aerosol Radiative Forcing	16
The Application of Regional Aerosol Properties to AVHRR Aerosol Retrieval Algorithms	17
Cloud Properties for ICE Analysis Using MODIS Data	18
METOC Data Assimilation and Modeling	19
Using the SHEBA Flux Data to Improve Regional and Global Climate Models	19
Evolution of Tropical Cyclone Characteristics	20
Numerical Hindcasts of the California Current	22
Decadal Teleconnections in the North Pacific and Globec - Northeast Pacific Climate Change Mechanisms	23
Evolution of Low-Level Flow Patterns in Littoral Regions when Extratropical Cyclones Encounter Coastal Mountains	24
Central California MESONET for use in LAPS and Local Mesoscale Modeling	25
Dependence of Mesoscale Coastal Predictability on Data Assimilation and Distribution of Observations	25
Tropical Cyclone Structure Changes	26
Mechanisms for Rapid Intensity Changes in Hurricanes	28
Aircraft Measurements and Analyses of the Cloudy Boundary Layers and Turbulence in the Arctic	29
Evaluations of Surface Flux and Boundary Parameterizations in COAMPS using Aircraft Measurements	29
Understanding the Evolution of Stratocumulus Clouds in the Coastal Zone	30
Entrainment and Layered Structure above the Stratocumulus Cloud Top	31
Numerical Modeling of Turbulence-Aerosol-Cloud Interaction	32
Collaborative Research Projects in Direct Support of FNMOC Operational Mission	32
TAMS-RT Verification and Evaluation	33
Support for METOC Sabbatical Visiting all CNMOC Regional Centers and Facilities	33
Boundary Layer Effects on Mesoscale Phenomena	34
Publications and Presentations	38
Thesis Abstracts	47
Improvement of METOC Analysis and Forecast Visualizations	47
Evaluation of Dynamical Track Predictions for Tropical Cyclones in the Atlantic During 1997-98	47
Error Analysis of Real-Time Remotely Sensed Microwave Sea-Ice Motions in the Western Arctic Ocean	48

TABLE OF CONTENTS

El Niño and La Niña Effects on Tropical Cyclones: The Mechanisms	48
Turbulence Profiles and Outer Length Scale Determination in the Atmosphere using Balloons.....	49
A Study on the Timing of the Southwest Monsoon Onset in the South China Sea	49
Large Eddy Simulation of Interactions Between Free Convection, Wind Driven Currents, and Baroclinicity in the Labrador Sea Deep Mixed Layers	50
Understanding Mesoscale Error Growth and Predictability	50
Estimation of Stratocumulus-Topped Boundary Layer Depth Using Sea Surface and Remotely Sensed Cloud-Top Temperatures	51
Optimization of MAS and MODIS Polar Ocean Cloud Mask	51
Forecasting Mesoscale Winds on Complex Terrain Using a Simple Diagnostic Model.....	52
Comparison of TAMS/RT Surface Wind, Temperature, and Pressure Fields with Surface Observations and Model Analyses in the SOCAL Area	52
Automated Meteorological and Oceanographic Data Collection and Distribution in Support of C4I, Weapons, and Remote Sensing Systems	53
Evaluation Study of the Tactical Atmospheric Modeling System/Real-Time (TAMS-RT) at NPMOC San Diego	53
Performance Evaluation of Integrated METOC Measurement System Supporting Naval Operations	54
Ambient Noise Characteristics during the SHEBA Experiment	54
A Composite Study of the Madden-Julian Oscillation (MJO) and Northeasterly Cold-Surges during the Northern Winter Monsoon	55
Suppression of Marine Stratocumulus Clouds due to Reduced Cloud Condensation Nuclei.....	56
Convective Activities within the Stratocumulus-Topped Boundary Layer	56
Initial Distribution List	57

PREFACE

Research at the Naval Postgraduate School is carried out by faculty in the four graduate schools (School of International Graduate Studies, Graduate School of Operations and Information Sciences, Graduate School of Engineering and Applied Sciences, and Graduate School of Business and Public Policy) and three Research Institutes (The Modeling, Virtual Environments, and Simulation (MOVES) Institute, Institute for Information Superiority and Innovation (I2SI), and Institute for Defense System Engineering and Analysis (IDSEA). This volume contains research summaries for the projects undertaken by faculty in the Department of Meteorology during 2000. The summary also contains thesis abstracts for those students advised by Meteorology faculty during 2000.

Questions about particular projects may be directed to the faculty Principal Investigator listed, the Department Chair, or the Department Associate Chair for Research. Questions may also be directed to the Office of the Associate Provost and Dean of Research. General questions about the Naval Postgraduate School Research Program should be directed to the Office of the Associate Provost and Dean of Research at (831) 656-2099 (voice) or research@nps.navy.mil (e-mail). Additional information is also available at the RESEARCH AT NPS website, <http://web.nps.navy.mil/~code09/>

Additional published information on the Naval Postgraduate School Research Program can be found in:

- *Compilation of Theses Abstracts:* A quarterly publication containing the abstracts of all unclassified theses by Naval Postgraduate School students.
- *Naval Postgraduate School Research:* A tri-annual (February, June, October) newsletter highlighting Naval Postgraduate School faculty and student research.
- *Summary of Research:* An annual publication containing research summaries for projects undertaken by the faculty of the Naval Postgraduate School.

This publication and those mentioned above can be found on-line at:
<http://web.nps.navy.mil/~code09/publications.html>.

INTRODUCTION

The research program at the Naval Postgraduate School exists to support the graduate education of our students. It does so by providing military relevant thesis topics that address issues from the current needs of the Fleet and Joint Forces to the science and technology that is required to sustain the long-term superiority of the Navy/DoD. It keeps our faculty current on Navy/DoD issues, to maintain the content of the upper division courses at the cutting edge of their disciplines. At the same time, the students and faculty together provide a very unique capability within the DoD for addressing warfighting problems. Our officers must be able to think innovatively and have the knowledge and skills that will let them apply technologies that are being rapidly developed in both the commercial and military sectors. Their unique knowledge of the operational Navy, when combined with a challenging thesis project that requires them to apply their focused graduate education, is one of the most effective methods for both solving Fleet problems and instilling the life-long capability for applying basic principles to the creative solution of complex problems.

The research program at the Naval Postgraduate School consists of both reimbursable (sponsored) and institutionally funded research. The research varies from very fundamental to very applied, from unclassified to all levels of classification.

- Reimbursable (Sponsored) Program: This program includes those projects externally funded on the basis of proposals submitted to outside sponsors by the School's faculty. These funds allow the faculty to interact closely with RDT&E program managers and high-level policymakers throughout the Navy, DoD, and other government agencies as well as with the private sector in defense-related technologies. The sponsored program utilizes Cooperative Research and Development Agreements (CRADAs) with private industry, participates in consortia with government laboratories and universities, provides off-campus courses either on-site at the recipient command, by VTC, or web-based, and provides short courses for technology updates.
- Naval Postgraduate School Institutionally Funded Research (NIFR) Program: The institutionally funded research program has several purposes: (1) to provide the initial support required for new faculty to establish a Navy/DoD relevant research area, (2) to provide support for major new initiatives that address near-term Fleet and OPNAV needs, (3) to enhance productive research that is reimbursably sponsored, and (4) to cost-share the support of a strong post-doctoral program.

In 2000, the level of research effort overall at the Naval Postgraduate School was 137 faculty work years and exceeded \$43 million. The reimbursable program has grown steadily to provide the faculty and staff support that is required to sustain a strong and viable graduate school in times of reduced budgets. In FY2000, over 93% of the research program was externally supported. A profile of the sponsorship of the Naval Postgraduate School Research Program in FY2000 is provided in Figure 1.

INTRODUCTION

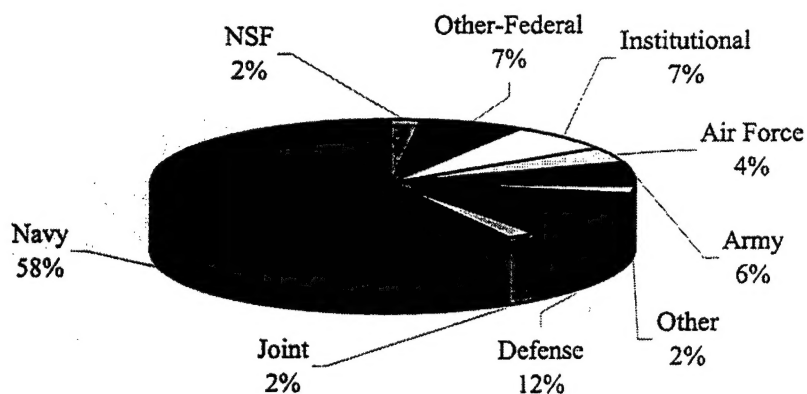


Figure 1. Profile of NPS Research and Sponsored Programs (\$43M)

The Office of Naval Research is the largest Navy external sponsor. The Naval Postgraduate School also supports the Systems Commands, Warfare Centers, Navy Labs and other Navy agencies. A profile of external Navy sponsorship for FY2000 is provided in Figure 2.

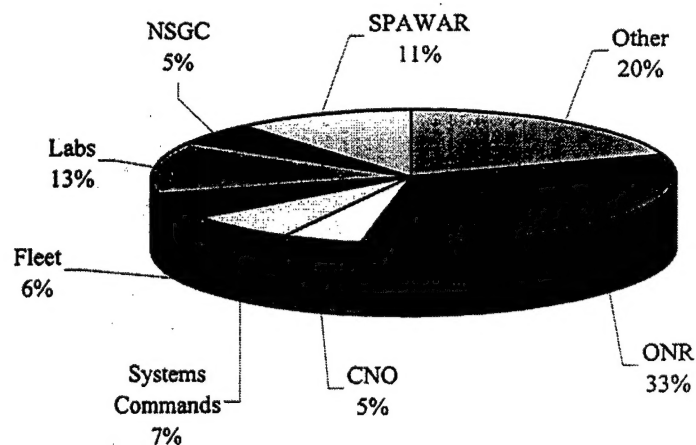


Figure 2. Navy External Sponsors of NPS Research and Sponsored Programs (\$25M)

These are both challenging and exciting times at the Naval Postgraduate School and the research program exists to help ensure that we remain unique in our ability to provide education for the warfighter.

DAVID W. NETZER
Associate Provost and Dean of Research

December 2001

**DEPARTMENT OF
METEOROLOGY**

**CARLYLE WASH
CHAIR**

DEPARTMENT SUMMARY

OVERVIEW:

The Department of Meteorology was founded in 1946 and throughout its history has had one of the leading meteorology programs in the country. The objective of the curricula is to provide students with a sound understanding of the science of meteorology and to develop the technical expertise to provide and utilize meteorological data and models in support of all aspects of weather-department operations.

CURRICULA SERVED:

- Meteorology
- Meteorology and Physical Oceanography

DEGREES GRANTED:

- Master of Science in Meteorology
- Master of Science in Meteorology and Physical Oceanography
- Doctor of Philosophy in Meteorology

RESEARCH THRUSTS:

- Synoptic, Mesoscale, and Coastal Meteorology:
Distinguished Professor Russell Elsberry, Associate Professor Wendell Nuss, Professor Carlyle Wash, Research Assistant Professor Douglas Miller
- Numerical Weather Prediction (NWP):
Professor Roger Williams, Research Associate Hway-Jen Chen, Research Assistant Professor Elizabeth Ritchie, Research Assistant Professor Douglas Miller
- Environmental Analysis and Visualization:
Research Associate Mary Jordan
- Air-Sea Interactions:
Professor Kenneth Davidson, Professor Robert Haney, Research Associate Paul Frederickson
- Satellite and Ground Based Remote Sensing:
Professor Phillip Durkee, Research Associate Kurt Nielsen
- Tropical Meteorology:
Professor Chih-Pei Chang, Research Associate Professor Lester Carr, Research Associate Hway-Chen, Research Associate Professor Patrick Harr, Research Assistant Professor Elizabeth Ritchie
- Tropical Cyclone Motion:
Distinguished Professor Russell Elsberry, Research Associate Professor Lester Carr, Research Associate Professor Patrick Harr
- Boundary Layer Meteorology:
Professor Kenneth Davidson, Assistant Professor Qing Wang, Research Fellow Ioannis Kalogiros
- Climate Dynamics:
Professor Chih-Pei Chang, Professor Roger Williams, Research Associate Hway-Jen Chen, Senior Lecturer Tom Murphee
- Atmospheric Factors in EM/EO Propagation:
Professor Kenneth Davidson, Research Associate Professor Peter Guest, Research Associate Paul Frederickson
- Polar Meteorology:
Research Associate Professor Peter Guest

DEPARTMENT SUMMARY

RESEARCH FACILITIES:

IDEA Laboratory

- The Interactive Digital Environmental Analysis (IDEA) laboratory has Silicon Graphics workstations specifically designed and funded for instruction. The lab computers analyze and display real-time satellite data and numerical model output.

Tactical Laboratory

- The Tactical Lab operates an SMQ-11 DMSP satellite receiver that collects and processes classified environmental data and runs military tactical decision aids used to support operations.

Synoptic Analysis and Forecasting Laboratory

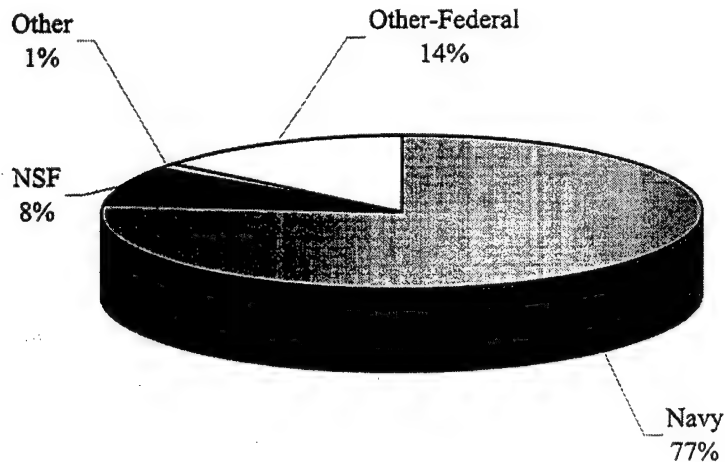
- The Synoptic Analysis and Forecasting Lab uses a suite of computers and advanced display devices to provide local and global real-time meteorological data and numerical products for instruction and research in operational weather forecasting.

Measurements Laboratory

- The Measurements Lab provides information from a special near-coastal observation site at Fort Ord in support of instruction and research in boundary layer and coastal meteorology. Present instrumentation includes two radar wind profilers, an automatic surface weather station, and rawinsonde systems.

RESEARCH PROGRAM-FY2000:

The Naval Postgraduate School's research program exceeded \$43 million in FY2000. Over 93% of the Naval Postgraduate School Research Program is externally funded. A profile of the external research sponsors for the Department of Meteorology is provided below along with the size of the FY2000 externally funded program.



Size of Program: \$2358K

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PROJECT SUMMARIES

MONSOON DISTURBANCES OVER THE CHINA SEAS

Chih-Pei Chang, Professor

Department of Meteorology

Sponsor: Office of Naval Research and Naval Postgraduate School

OBJECTIVE: The objectives are: (1) to study the structure and the dynamic and thermodynamic properties of the disturbances in the vicinity of the Southeast and East Asian monsoon region that stretches from Indian Ocean to the tropical western Pacific, including the South China Sea and Yellow Sea, which are of particular interest to naval operations; and (2) to study the ability and sensitivity of Navy operational numerical models in analyzing and predicting these disturbances.

SUMMARY: During northern winter monsoon, the Madden-Julian Oscillation (MJO) and northeasterly cold surges are active over the tropical eastern Indian Ocean and western Pacific. Taylor (1998) has shown that both motion systems are important in the development of tropical cyclones. We examined the interactions between the two motion systems during the 1979-1998 period using the NCEP Reanalysis 1000 hPa wind and OLR data. Based on the linear equatorial dynamics theory with anomalous heating (Gill 1980, Lau and Peng 1987), the MJO circulation and convection patterns can be represented by a combination of Rossby and Kelvin wave responses. During the MJO active phase, enhanced convection over the equatorial region of the South China Sea produces lower pressure and therefore a stronger pressure gradient that favors cold surge. However, the cyclonic flow associated with the Rossby mode response in the northern subtropics produces southwesterlies in the northern South China Sea and opposes the surge. The net results of these competing effects are analyzed by dividing the MJO into four phases (early active, late active, early inactive, late inactive) in the South China Sea, and the cold surge events into two stages: (day 1-6 and day 7-12, with day 0 defined as the day of minimum northerly in northern South China Sea).

During the early active phase, the MJO convection helps intensify the cold surge by creating an area of lower pressure. Surges are longer in duration as a result of MJO convection persisting over the area. For the early inactive phase, the lack of organized MJO convection hinders the surge. However, a few surges occur in this phase as a result of mid-latitude forcing. As the early inactive phase progresses out to day 7-12, the surges are no longer present. During surge day 1-6 of the late active phase, the MJO convection helps to intensify the surge events. The Rossby mode pressure-wind pattern opposes the surge, but its effect is dominated by the convective effects of the MJO. As a result, this period contains the highest frequency of surges. Later into the period (day 7-12), the MJO convection moves out of the South China Sea so surges are hindered by the Rossby mode pressure-wind relationship. During the late inactive phase, the Rossby mode pressure-wind pattern helps the surge for surge day 1-6. However, the surge is hindered by the lack of the MJO convection that tends to be associated with anomalously higher surface pressure in the equatorial South China Sea. The frequency of surges is therefore minimum in this situation. Later in the period (surge day 7-12), the MJO dry segment moves out of the area, the monsoon surges are helped by the pressure wind pattern and the frequency of surges increases.

PUBLICATION:

Chang, C. -P., L. Yi, George, T.J., and Chen, H.J., 2000: A numerical simulation of vortex development during the 1992 East Asian summer monsoon onset using the Navy's regional model, *Monthly Weather Review*, 128, 1604-1631.

THESES DIRECTED:

Simms, J.W., IV, "A Composite Study of the Madden-Julian Oscillation and Northeasterly Cold Surges during the Northern Winter Monsoon," Masters Thesis, Naval Postgraduate School, March 2000.

Gedult von Jungenfeld, Eric F.C., "A Study of the Southwest Monsoon Onset in the South China Sea," Masters Thesis, Naval Postgraduate School, June 2000.

DoD KEY TECHNOLOGY AREAS: Environmental Quality, Modeling and Simulation

KEYWORDS: Tropical Meteorology, Monsoon, China Seas

PROJECT SUMMARIES

EAST ASIAN MONSOON AND TROPOSPHERIC BIENNIAL OSCILLATIONS

Chih-Pei Chang, Professor

Department of Meteorology

Sponsor: National Science Foundation

OBJECTIVE: To study the structure of the interannual variations of the Asian-Australian monsoon and its relationship with El Nino – Southern Oscillations (ENSO).

SUMMARY: The relationship between Asian monsoon and ENSO was studied using data analysis, simple dynamic modeling and numerical modeling. The studies reveal complex interaction between different climate parameters and underscore the variable nature of the relationships at different time scales, from biennial to interdecadal.

PUBLICATIONS:

Li, T., Hogan, T.F., and Chang, C.P., 1999: Dynamic and thermodynamic regulation of ocean warming, *Journal of Climate*.

Chang, C. -P. and Li, T., 2000: A Theory for Tropical Tropospheric Biennial Oscillation, *Journal of Atmospheric Sciences*, 57, 2209-2224.

Li, T., Hogan, T.F., and Chang, C.P., 2000: Dynamic and Thermodynamic Regulation of Ocean Warming, *Journal of Atmospheric Sciences*, 20, 3353-3365.

Chang, C. -P., Zhang, Y., and Li, T., 2000: Interannual and Interdecadal Variation of the East Asian Summer Monsoon Rainfall and Tropical SSTs, Part 1: Roles of the Subtropical Ridge, 13, *Journal of Climate*, 4310-4325.

Chang, C. -P., Zhang, Y., and Li, T., 2000: Interannual and Interdecadal Variation of the East Asian Summer Monsoon Rainfall and Tropical SSTs, Part 2: Meridional Structure of the Monsoon, *Journal of Climate*, 13, 4326-4340.

Li, T., Tham, C.W., and Chang, C.P., 2000: A Coupled Air-Sea-Monsoon Oscillator for the TBO, *Journal of Climate*, accepted.

Kuo, H. -C., Chen, J.H., Williams, R.T., and Chang, C.P., 2001: Rossby Waves in Zonally Opposing Mean Flow: Behavior in Northwest Pacific Summer Monsoon, *Journal of Atmospheric Sciences*, accepted.

Chang, C. -P., Harr, P.A., and Ju, J., 2001: Possible Roles of Atlantic Circulations on the Weakening Indian Monsoon ENSO relationship, 14, *Journal of Climate*, (Letters), in press.

PRESENTATIONS:

Chang, C. -P., Harr, P.A., and Ju, J., 2000: North Atlantic Oscillation/Arctic Oscillation and the Weakening Indian Monsoon-ENSO Relationship, U.S.-Japan Monsoon Workshop, Goddard Space Flight Center, NASA, November 2000.

Li, T., Zhang, Y., Chang, C.P., and Wang, B., 2000: Monsoon Biennial and Low Frequency Modes and relationship with ENSO, US-Japan Monsoon Workshop, Goddard Space Flight Center, NASA, November 2000.

DoD KEY TECHNOLOGY AREAS: Environmental Quality, Modeling and Simulation

KEYWORDS: Monsoon, Air-Sea Interactions, Biennial Oscillations, El Niño, Climate Variations

PROJECT SUMMARIES

DEVELOPMENT OF AN EXPERT SYSTEM BASED ON THE SYSTEMATIC APPROACH TO TROPICAL CYCLONE TRACK FORECASTING

Lester E. Carr, III, Research Associate Professor

Russell L. Elsberry, Distinguished Professor

Department of Meteorology

Sponsor: Office of Naval Research

OBJECTIVE: The objectives of this project are to conduct exploratory research to: (i) develop a prototype expert system that is based on the Systematic Approach to Tropical Cyclone (TC) Track Forecasting concept, and which methodically leads the TC forecaster through a sound forecast formulation process, exposes the forecaster to key information, prompts and assists the forecaster to make pivotal decisions, and accomplishes basic tasks for the forecaster wherever feasible; and (ii) demonstrate the feasibility of such an expert system for improving the accuracy and meteorological utility of official tropical cyclone track forecasts.

SUMMARY: This project is a continuation from 1999. The Systematic Approach Forecasting Aid (SAFA) expert system prototype, which was beta tested by NPS in 1999, was upgraded and subjected to a season-long operational test by the forecasters at the Joint Typhoon Warning Center (JTWC). Prior to the test, a set of web-based training modules was developed to assist the JTWC forecasters in preparing to use SAFA under operational conditions. During the test, the results being obtained by JTWC were periodically monitored, and after the test a statistical analysis and a forecast-by-forecast evaluation of 300 plus Non-selective Consensus (NCON) and Selective Consensus (SCON) 72-h forecasts made by JTWC was conducted. The test was partly successful in that JTWC attributed the use of SAFA as a significant factor in their record low average forecast track errors (209 n mi at 72 h compared to 234 n mi in 1999) in the western North Pacific during 2000. However, the post-season evaluation revealed that JTWC's employment of SAFA was not optimal, and that further significant reduction in the SCON forecast errors could be achieved via a combination of hardware, software, knowledge base and procedural improvements. These improvements will be implemented during the first half of CY2001 in preparation for operational use of SAFA in the western North Pacific during the 2001 TC season.

PUBLICATIONS:

Carr, L.E., III, Elsberry, R.L., and Peak, J.E., 2000: Beta test of the Systematic Approach expert system prototype as a tropical cyclone track forecasting aid (SAFA), *Weather Forecasting*, in press.

Carr, L.E. III, Elsberry, R.L., Peak, J.E., and Dunnavan, G. M., 2000: Development and beta-test of the Systematic Approach expert system prototype as a tropical cyclone track Forecasting Aid (SAFA), Naval Postgraduate School Technical Report, NPS-MR-00-002, 67 pp.

Carr, L.E., III, Dunnavan, G.M., Elsberry, R.L., Boothe, M.A., and Harr, P.A., 2000: Developing a systematic approach to tropical cyclone track expert system-2: Results of a real-time prototype test, *Preprints, 24th Conference on Hurricane Tropical Meteorology*, American Meteorology Society, Boston, MA 02108, pp. 504-505.

Elsberry, R.L., and Carr, L.E., III, 2000a: Consensus of dynamical tropical cyclone track forecasts—Errors versus spread, *Monthly Weather Review*, 128, 4131-4138.

Elsberry, R.L. and Carr, L.E., III, 2000b: Applying clustering and ensemble prediction concepts to consensus tropical cyclone track forecasting, *Preprints, 24th Conference on Hurricane Tropical Meteorology*, American Meteorology Society, Boston, MA, pp. 431-432.

Peak, J.E., Carr, L.E., III and Elsberry, R.L., 2000: Developing a systematic approach to tropical cyclone track forecasting expert system -1: Information management, visualization, and proactivity considerations, *Preprints, 24th Conference on Hurricane Tropical Meteorology*, Ft. Lauderdale, FL, American Meteorology Society, pp. 502-503.

PROJECT SUMMARIES

PRESENTATION:

Elsberry, R.L., 2000: Overview of the Systematic Approach to tropical cyclone track forecasting, USCINCPAC Tropical Cyclone Conference, Tokyo, Japan, 28 February-1 March 2000.

OTHER:

This project has resulted in the creation of a software product called the Systematic Approach to Tropical Cyclone Track Forecasting Aid (SAFA) that runs on Silicon Graphics and Hewlett Packard Unix workstations. The software code has a highly sophisticated and interactive graphical user interface and was written by programmers at the Monterey office of Computer Sciences Corporation (CSC) under the leadership of J. Peak.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Tropical Cyclone Prediction, Expert Systems

APPLICATION OF THE SYSTEMATIC APPROACH TO TROPICAL CYCLONE TRACK FORECASTING IN THE WESTERN NORTH PACIFIC AND EXTENSION TO OTHER TROPICAL CYCLONE REGIONS

Lester E. Carr, III, Research Associate Professor

Russell L. Elsberry, Distinguished Professor

Department of Meteorology

Sponsor: Space and Naval Warfare Systems Command

OBJECTIVE: The focus of this project is the extension of the Systematic Approach concept to various regions of the world where tropical cyclones (TC) form. Thus, this project is the transition of an ONR project entitled Systematic Approach to Tropical Cyclone Track Forecasting, which has to do with the formulation of the overall systematic approach to tropical cyclone forecasting "concept," particularly the development of meteorological knowledge bases to explain and forecast tropical cyclone motion in the western North Pacific.

SUMMARY: Collaboration with the Perth office of the Australian Bureau of Meteorology has continued as in previous years, and has resulted in the continuing development and enlargement of a dynamical model traits knowledge base for the South Pacific and South Indian Ocean regions, which documents the frequencies of the various error mechanisms that resulted in 72-h forecast track errors exceeding 300 n mi. In addition, the Southern Hemisphere meteorological knowledge based was converted from a hard-copy report format into a web-based training module and delivered to JTWC in December for use during the 2001 Southern Hemisphere TC season. For the north Atlantic basin, the initial development of model traits knowledge base was completed and documented via a masters thesis. Work to refine the model traits knowledge base for the western North Pacific by including additional years of NOGAPS and GFDN forecasts and expanding the knowledge base to include foreign agency TC track forecasting models (UK Meteorological Office and European Center for Medium-range Forecasts) was also completed.

PUBLICATIONS:

Brown, D.S., Boothe, M.A., Carr, L.E., III, and Elsberry, R. L., 2000: Evaluation of dynamical track predictions for tropical cyclones in the Atlantic during 1997-1998, *Preprints, 24th Conference on Hurricane Tropical Meteorology*, American Meteorology Society, Boston, MA, pp. 390-391.

Carr, L.E., III, and Elsberry, R.L., 2000a: Dynamical tropical cyclone track forecast errors, Part I, Tropical region error sources, *Weather Forecasting*, 15, pp. 641-661.

Carr, L.E., III, and Elsberry, R.L., 2000a: Dynamical tropical cyclone track forecast errors, Part II, Midlatitude circulation influences, *Weather Forecasting*, 15, pp. 662-681.

PROJECT SUMMARIES

Dunnavan, G.M., Carr, L.E., III, Elsberry, R.L., and Boothe, M.A., 2000: Evaluation of dynamical track predictions for tropical cyclones in the western North Pacific: Extensions to other years and dynamical models, *Preprints, 24th Conference on Hurricane Tropical Meteorology*, American Meteorology Society, Boston, MA 02108, pp. 384-385.

Reader, G., Boothe, M.A., Elsberry, R.L., and Carr, L.E., III, 2000a: Southern Hemisphere application of the Systematic Approach to tropical cyclone forecasting, Part IV: Source of large track errors by dynamical models, Naval Postgraduate School Technical Report, NPS-MR-00-004, 51 pp.

Reader, G., Boothe, M.A., Elsberry, R.L., and Carr, L.E., III, 2000b: Updated environmental structure characteristic for Southern Hemisphere application of the systematic approach to tropical cyclone track forecasting, *Preprints, 24th Conference on Hurricane Tropical Meteorology*, American Meteorology Society, Boston, MA 02108, pp. 167-168.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Tropical Cyclone Motion, Tropical Cyclone Prediction

EVALUATION OF TDROP FOR USE IN THE MARINE ATMOSPHERIC BOUNDARY LAYER

**K. L. Davidson, Professor
Department of Meteorology**

Sponsor: Space and Naval Warfare Systems Command

OBJECTIVE: Validate/verify the Tactical Drop-sondes (TDrop) to meet requirements for accurate and tactically significant measurements of temperature, moisture, and pressure within the lower marine atmosphere.

SUMMARY: Evaluation testing was performed to validate that the performance of the installed TDrop sensor suite was comparable to off-the-shelf atmospheric sondes currently available to DoD. Specifically, the accuracy and resolution of the TDrop sensors for measuring atmospheric pressure, temperature and relative humidity were evaluated. The procedures for TDrop testing were carried out in three phases:

- Phase I: Static instrument chamber tests conducted at the National Institute of Standards and technology (NIST) during the week of 11 September 2000.
- Phase II: Dynamic sensor verification/comparison tests conducted at Wallops Island, VA, during the week of 2 October 2000.
- Phase III: Airborne/Atmospheric Characterization tests conducted in Monterey Bay, CA, during the week of 16 October 2000.

PUBLICATIONS:

Davidson, K.L. and Ranard, D., "NIST Instrument Chamber Static Test Results: BAE-TDrop," Naval Postgraduate School Technical Report, NPS-MR-01-001, November 2000.

Frederickson, P.A. and Davidson, K.L., "Results of the TDrop Dynamic Comparison Test (Phase II)," Naval Postgraduate School Technical Report, NPS-MR-01-002, November 2000.

Guest, P.S., Davidson, K.L., and Frederickson, P.A., "Monterey Bay Airborne/Atmosphere Characterization Test Results: BAE-T drip (Phase III)," Naval Postgraduate School Technical Report, NPS-MR-01-003, November 2000, 47 pp.

Guest, P.S., Davidson, K.L., and Frederickson, P.A., "Analyses of TDrop Performance Parameters from Static and Dynamic Tests," Naval Postgraduate School Technical Report, NPS-MR-01-004, November 2000, 21 pp.

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Davidson, K.L. and Ranard, D., "TDrop Static and Dynamic Tests Final Report," Naval Postgraduate School Technical Report, NPS-MR-01-005, November 2000.

OTHER:

Davidson, K.L., "TDrop Test Plan for Laboratory Static Calibration Test (NIST)," September 2000.

Frederickson, P.A. and Davidson, K.L., "Test Plan for Wallops Island Dynamic Comparison Test," October 2000.

Davidson, K.L., "TDrop Test Plan for Test Ship and Test Aircraft Monterey Bay," October 2000.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Sensors

KEYWORDS: Meteorological Measurement, Marine Atmosphere Boundary Layer

METOC DATA ACQUISITION (MORIAH)

K. L. Davidson, Professor

Department of Meteorology

Sponsor: Space and Naval Warfare Systems Command

OBJECTIVE: Support acquisition strategy of a shipboard Meteorology and Oceanography parameter sensor system, MORIAH, by carrying out validation, verification and integration procedures. Prepare software documentation for acquisition and evaporation duct calculation.

SUMMARY: NPS evaluated and documented performance characteristics of MORIAH hardware and Software for use in the complex METOC and electronic environment of a Navy warship operating in the North Atlantic, the Mediterranean and in the Persian Gulf. These were also done for MORIAH like systems mounted on buoys deployed in coastal regimes in support of propagation tests. The ship data were collected by the JHU/APL SEAWASP system, a prototype MORIAH system. Examinations of METOC data measurement were of hardware component performance with regard to MORIAH MNS requirements. Ship and buoy hardware included mounted, and deployed (floatsonde and rocketsonde) sensors. System performance evaluation was of characteristics of both the MORIAH hardware and acquisition and calculation/editing software. Documentation was performed of algorithms for calculating METOC variables and evaporation duct within the MORIAH system.

PUBLICATIONS:

Frederickson, P., Davidson, K.L., and Goroch, A.K., 2000, "Operational Bulk Evaporation Duct Model for MORIAH," Naval Postgraduate School Technical Report, NPS-MR-2000-002, 5 May 2000, pp. 69.

Goroch, A.K., Jordan, M., Frederickson, P., and Davidson, K.L., "Standard Meteorological Equations and Algorithms Used in MORIAH Processing," NRL/Naval Postgraduate School Report, June 2000, 105 pp.

Frederickson, P.A. and Davidson, K.L., "A Sensitivity and Convergence Analysis of a Bulk Air-Sea Flux Model," *Preprints, 14th Symposium on Boundary Layers and Turbulence*, Aspen, CO, American Meteorological Society, pp. 298-301, 7-11 August 2000.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Sensors

KEYWORDS: Meteorological Measurement, Marine Atmosphere Boundary Layer

PROJECT SUMMARIES

OPERATIONAL METOC MEASUREMENT SYSTEMS (METCAST)

K. L. Davidson, Professor

Department of Meteorology

Sponsor: Space and Naval Warfare Systems Command

OBJECTIVE: Provide technical guidance in MORIAH ORD/RFP preparations. Perform special analysis and interpretation on sensor and model requirements. Evaluate merging of technologies for regional EM/EO assessments.

SUMMARY: Techniques demonstrate the capability of automated record keeping, with the potential of electronic transmission and receipt of METOC data at sea. Demonstrated the capability to automate transmission of continuous METOC data to central METOC fleet support / production centers using COTS hardware and software. Additionally, developed was a prototype computer based application for logging METOC observation data and preparing routine required reports. This represents a substantial advance in METOC record keeping, delivery to a central site, and sharing within the fleet.

THESIS DIRECTED:

Nisley, W.H., II, "Automated Meteorological and Oceanographic Data Collection and Distribution in Support of C4I, Weapons, and Remote Sensing Systems," Masters Thesis, Naval Postgraduate School, September 2000.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Meteorological Measurement, METOC Data Transfer

BUOY MEASUREMENT OF ATMOSPHERIC SURFACE-LAYER MEAN AND TURBULENT/FLUX PARAMETERS AND SURFACE WAVES: SUPPORT OF ICON AND MUSE/AOSN

K. L. Davidson, Professor

Department of Meteorology

Sponsor: Office of Naval Research

OBJECTIVE: Obtain continuous buoy-based descriptions of airflow mean and turbulent/flux and surface temperature and wave properties during oceanographic ICON and MUSE/AOSN investigations in Monterey Bay.

SUMMARY: NPS personnel and equipment provided collection of near-surface and surface environmental measurements from an instrumented buoy in Monterey Bay during two oceanography formulated experiments; ICON and MUSE/AOSN. The NPS 'Flux' buoy was deployed off Moss Landing, CA for two periods of approximately nine weeks each, from the 1st week of September to mid-November 1999 and from mid-January 2000 to mid March 2000 for ICON and for a period of approximately 10 weeks, from the 1st week of August to the 1st week of November 2000 for MUSE/AOSN. Both mean and turbulent measurements from the buoy were obtained to describe near-surface forcing of the ocean and buoy motion measurements were made to describe surface wave properties. Real-time Rf transmission of the some data occurred and edited and analyzed data sets from NPS buoy were provided to NPS and CSUMB oceanography investigators performing remote sensing of ocean properties (ICON) and modeling of meso-scale features upper Monterey Bay (MUSE/AOSN).

OTHER: Frederickson, P.A., Davidson, K.L., Jones, F.K., and Neta, T., "FLUX Buoy Data Report, ICON September-November 1999 Deployment in Monterey Bay, CA," 20 February 2000, 29 pp.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Sensors

PROJECT SUMMARIES

KEYWORDS: Meteorological Measurement, Marine Atmosphere Boundary Layer, Surface Fluxes, Waves

NEAR-SURFACE SCALAR PROFILES IN WALLOPS '00: FLUX-BUOY MEASUREMENTS, ANALYSES, AND PHYSICAL MODELING

K. L. Davidson, Professor

Department of Meteorology

Sponsor: Naval Surface Warfare Center-Dahlgren Division

OBJECTIVE: Obtain near-surface atmospheric and surface data that will enable gradients of the radar/radio wave refractivity and wave conditions to be estimated for interpretation of near-horizon EM propagation.

SUMMARY: NPS personnel and equipment were involved in the collection of near-surface and surface environmental measurements from an instrumented buoy in support of the Wallops'00 propagation experiment. The NPS 'Flux' buoy was deployed off Wallops Island, VA, for a period of approximately six weeks, from 1 April through mid-May 2000. Both mean and turbulent measurements from the buoy were made to describe near-surface refractivity profiles and buoy motion measurements were made to describe surface wave properties. Edited and analyzed data sets from NPS buoy were provided to NSWC-DD persons performing analyses of Rf propagation conditions during the period.

PRESENTATION:

Davidson, K.L., Frederickson, P.A., and Gorocho, A.K., "Analysis and Validation of an Operational Bulk Surface-Layer (Evaporation Duct) Model," National Radio Science Meeting (URSI), Boulder, CO, 5-8 January 2000.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Sensors

KEYWORDS: Meteorological Measurement, Marine Atmosphere Boundary Layer, Optical Transmission, Rf Transmission

ATMOSPHERIC CIMREP (ADVANCED PROPAGATION MODEL)

K. L. Davidson, Professor

Peter Guest, Associate Research Professor

Department of Meteorology

Sponsor: Naval Meteorology and Oceanography Command

OBJECTIVE: Coordinate and serve as members of a COMNOAVMETOCCOM Independent Model Review and Evaluation Panel (CIMREP) for the Atmosphere. The model evaluated is the Advanced Propagation Model (APM) submitted for inclusion in Oceanographic and Atmospheric Master Library (OAML).

SUMMARY: Professor Kenneth L. Davidson and Dr. Peter Guest were NPS participants in the CIMREP. Arrangements were made for several propagation model experts to be members of the CIMREP. Members were from NSWC-DD, SSC, PSU, and JHU/APL as well as NPS. The CIMREP for the Advanced Propagation Model (APM), version 1.0, was planned for February-September 2000 timeframe. A "kick off" meeting was held during week of 20 March 2000 at NPS with most members present. A second and final meeting was held at the Pennsylvania State University, State College PA during the week of 2 September 2000. The CIMREP members reviewed the submitted APM documents and ran the APM code. APM developers at the SSC-SD, Tropospheric Branch, (Code D883) were interviewed to understand aspects of the model and their testing methodology. Final report was prepared and submitted to sponsor in February 2001.

PROJECT SUMMARIES

OTHER:

APM CIMREP Committee, 2001: Technical Review of the Advanced Propagation Model (APM) – A Report by the APM CIMREP Panel, submitted to Commander, Naval Meteorology and Oceanography Command, Stennis Space Center, 14 February 2000, 141 pp.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Sensors

KEYWORDS: Rf Transmission, Propagation Model, Marine Atmosphere Boundary Layer

SCALING NEAR-SURFACE ATMOSPHERE AND WAVE INFLUENCES ON Rf/EO PROPAGATION OVER THE SEA

K. L. Davidson, Professor
Department of Meteorology
Sponsor: Office of Naval Research

OBJECTIVE: Improve models for describing near horizon Rf/EO propagation through evaluation of the Monin-Obukhov surface-layer scaling for near surface turbulence and refractivity gradients.

SUMMARY: Analyses and interpretations were performed on near-surface refractive gradients, turbulent transport, and surface wave data obtained from buoys during coordinated experiments. The Rf data were from combined collections of in situ and propagation (Rf) off Wallops Island, VA during the spring (March through May) of 1998 and 2000. The EO data were from combined collections of in situ and propagation (EO) in San Diego Bay, CA and Duck NC from 1996 through 1998. Collaborative analyses/interpretations during preceding field experiment years emphasized mean airflow properties. Our own interpretations addressed the use of current bulk methods for estimating optical turbulence (C_n^2) and scaling parameters (T , q , and u). Waves influences have been addressed to qualitatively identify the influence. Existing results demonstrate that current models perform well in unstable conditions but clearly not in stable conditions.

PUBLICATIONS:

Frederickson, P.A., Davidson, K.L., Zeisse, C.R., and Bendall, C.S., "Estimating the Refractive Index Structure Parameter (C_n^2) Over the Ocean Using Bulk Methods," *Journal of Applied Meteorology*, Vol. 39, pp. 1770-1783, October 2000.

Jensen, D.R., Gathman, S.G., Zeisse, C.R., McGrath, C.P., de Leeuw, G., Smith, M.H., Frederickson, P.A., and Davidson, K.L., "Electro-optical Propagation Assessment in Coastal Environments (EOPACE) Summary and Accomplishments," *Optical Engineering*, accepted for publication, 2001.

Zeisse, C.R., Barrios, A.E., Doss-Hammel, S.M., de Leeuw, G., Moerman, M., de Jong, A.N., Frederickson, P.A., and Davidson, K.L., "Low Altitude Infrared Propagation Over the Ocean," *Applied Optics*, accepted for publication, 2001.

Frederickson, P.A., and Davidson, K.L., "Air-Sea Flux Measurements From a Buoy in a Coastal Ocean Region," *Preprints, 14th Symposium on Boundary Layers and Turbulence*, Aspen, CO, American Meteorological Society, pp. 530-533, 7-11 August 2000.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Sensors

KEYWORDS: Meteorological Measurement, Marine Atmosphere Boundary Layer, Optical Transmission, Rf Transmission

PROJECT SUMMARIES

DEVELOPMENT AND VALIDATION OF MULTIPLE-SATELLITE DATA SETS FOR GLOBAL AEROSOL RADIATIVE FORCING

Philip A. Durkee, Professor

Department of Meteorology

Sponsor: National Aeronautics and Space Administration

OBJECTIVE: This proposal seeks support to develop multiple-satellite aerosol optical depth retrieval methods for global-scale analysis of radiative forcing. Validation methods will include data and experience gained in participation in numerous recent field programs.

SUMMARY: This was the second year of this three-year project. Extensive validation activities have been conducted using the ACE-2 and TARFOX data sets: 1) Comparisons of surface, shipboard, and aircraft sunphotometers with satellite retrievals. (TARFOX, ACE-2, Aerosols99/INDOEX); 2) Tests of aerosol model assumptions against in situ aircraft measurements of aerosol properties such size distribution, composition, and resulting radiative properties; 3) Validation within the context of complete column closure studies is continuing; 4) Tests of the effects of sunglint and cloud screening techniques; Regional analysis of optical depth including wavelength variation and variation statistics was conducted for the 5) recent aerosol experiments (ACE-1, TARFOX, ACE-2, and Aerosols99/INDOEX); and 6) Development of retrievals from combined NOAA AVHRR and GOES are in progress. Validation of these techniques includes observations from TARFOX, EOPACE, and recent observations off the U.S. West Coast.

PUBLICATIONS:

Durkee, P.A., Nielsen, K.E., Smith, P.J., Russell, P.B., Schmid, B., Livingston, J.M., Holben, B.N., Tomasi, C., Vitale, V., Collins, D., Flagan, R.C., Seinfeld, J.H., Noone, K.J., Öström, E., Gasso, S., Hegg, D., Russell, L.M., Bates, T.S., and Quinn, P.K., "Regional aerosol optical depth characteristics from satellite observations: ACE-1, TARFOX and ACE-2 results," *Tellus*, 52B, pp. 484-497.

Gasso, S., Hegg, D.A., Covert, D.S., Collins, D., Noone, K.J., Öström, E., Schmid, B., Russell, P.B., Livingston, J.M., Durkee, P.A., and Jonsson, H., "Influence of humidity on the aerosol scattering coefficient and its effect on the upwelling radiance during ACE2," *Tellus*, 52B, pp. 546-567.

Schmid, B., Livingston, J.M., Russell, P.B., Durkee, P.A., Jonsson, H.H., Collins, D.R., Flagan, R.C., Seinfeld, J.H., Gasso, S., Hegg, D.A., Ostrom, E., Noone, K.J., Welton, E.J., Voss, K.J., Gordon, H.R., Formenti, P., and Andreae, M.O., "Clear-sky closure studies of lower tropospheric aerosol and water vapor during ACE-2 using airborne sunphotometer, airborne in-situ, space-borne and ground based measurements," *Tellus*, 52B, pp. 568-593.

Livingston, J.M., Kapustin, V.N., Schmid, B., Russell, P.B., Quinn, P.K., Bates, T.S., Durkee, P.A., Smith, P.J., Freudenthaler, V., Wiegner, M., Covert, D.S., Gasso, S., Hegg, D., Collins, D.R., Flagan, R.C., Seinfeld, J.H., Vitale, V., and Tomasi, C., "Shipboard sunphotometer measurements of aerosol optical depth spectra and columnar water vapor during ACE-2 and comparison with selected land, ship, aircraft, and satellite measurements," *Tellus*, 52B, pp. 594-619.

Welton, E.J., Voss, K.J., Gordon, H.R., Maring, H., Smirnov, A., Holben, B., Schmid, B., Livingston, J.M., Russell, P.B., Durkee, P.A., Formenti, P., and Andrea, M.O., "Ground-based lidar measurements of aerosols during ACE-2: instrument description, results, and comparisons with other ground-based and airborne measurements," *Tellus*, 52B, pp. 636-651.

Johnson, D.W., Osborne, S., Wood, R., Suhre, K., Johnson, R., Businger, S., Quinn, P.K., Wiedensohler, A., Durkee, P.A., Russell, L.M., Andreae, M.O., O'Dowd, C., Noone, K.J., Bandy, B., Rudolph, J., and Rapsomanikis, S., "An overview of the Lagrangian experiments undertaken during the North Atlantic Regional Aerosol Characterization Experiment (ACE-2)," *Tellus*, 52B, pp. 290-320.

PROJECT SUMMARIES

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEY WORDS: Satellite, Remote Sensing, Aerosol Processes, Atmospheric Radiation

THE APPLICATION OF REGIONAL AEROSOL PROPERTIES TO AVHRR AEROSOL RETRIEVAL ALGORITHMS

Philip A. Durkee, Professor

Department of Meteorology

**Sponsors: National Oceanic and Atmospheric Administration and
Pacific Marine Environmental Laboratory**

OBJECTIVE: The object of this project is to analyze, compare and integrate shipboard measured aerosol optical with AVHRR (Advanced Very High-Resolution Radiometer) satellite retrievals of aerosol properties. NOAA PMEL has conducted several cruises in the Pacific, Atlantic and Indian Oceans over the past 10 years. NPS has cooperated with PMEL to collect AVHRR data coincident with these cruises. The data sets will provide the basis for regional improvements to satellite retrievals of aerosol properties under GACP.

SUMMARY: NPS has retrieved AOD for all available midday AVHRR collected during the RITS-II cruise in the fall of 1993. In addition, these data have been binned onto a 0.1-deg x 0.1-deg grid for compositing and statistical analysis. Attention has been focused on the midday AVHRR due to the reduced error associated with maximum daylight. In the case of RITS-II data, the very clean conditions observed during the cruise resulted in AOD values of zero being retrieved in many places. These are regions near the minimum sensitivity of the AVHRR optical sensor, and this suggests a careful interpretation of the retrievals before performing the final composite. We are in the process of composite analysis for the remaining RITS cruise (spring 1993) dataset and the CSP cruise (spring 1996) dataset. Results from the binned and composited datasets from INDOEX (both 1-km LAC and 4-km GAC datasets) were presented at the AGU meeting in December of 1999.

PUBLICATIONS:

Durkee, P.A., Nielsen, K.E., Smith, P.J., Russell, P.B., Schmid, B., Livingston, J.M., Holben, B.N., Tomasi, C., Vitale, V., Collins, D., Flagan, R.C., Seinfeld, J.H., Noone, K.J., Öström, E., Gassò, S., Hegg, D., Russell, L.M., Bates, T.S., and Quinn, P.K., "Regional aerosol optical depth characteristics from satellite observations: ACE-1, TARFOX and ACE-2 results," *Tellus*, 52B, pp. 484-497.

Gassò, S., Hegg, D.A., Covert, D.S., Collins, D., Noone, K.J., Öström, E., Schmid, B., Russell, P.B., Livingston, J.M., Durkee, P.A., and Jonsson, H., "Influence of humidity on the aerosol scattering coefficient and its effect on the upwelling radiance during ACE2," *Tellus*, 52B, pp. 546-567.

Schmid, B., Livingston, J.M., Russell, P.B., Durkee, P.A., Jonsson, H.H., Collins, D.R., Flagan, R.C., Seinfeld, J.H., Gasso, S., Hegg, D.A., Ostrom, E., Noone, K.J., Welton, E.J., Voss, K.J., Gordon, H.R., Formenti, P., and Andreae, M.O., "Clear-sky closure studies of lower tropospheric aerosol and water vapor during ACE-2 using airborne sunphotometer, airborne in-situ, space-borne and ground based measurements," *Tellus*, 52B, pp. 568-593.

Livingston, J.M., Kapustin, V.N., Schmid, B., Russell, P.B., Quinn, P.K., Bates, T.S., Durkee, P.A., Smith, P.J., Freudenthaler, V., Wiegner, M., Covert, D.S., Gasso, S., Hegg, D., Collins, D.R., Flagan, R.C., Seinfeld, J.H., Vitale, V., and Tomasi, C., "Shipboard sunphotometer measurements of aerosol optical depth spectra and columnar water vapor during ACE-2 and comparison with selected land, ship, aircraft, and satellite measurements," *Tellus*, 52B, pp. 594-619.

Welton, E.J., Voss, K.J., Gordon, H.R., Maring, H., Smirnov, A., Holben, B., Schmid, B., Livingston, J.M., Russell, P.B., Durkee, P.A., Formenti, P., and Andreae, M.O., "Ground-based lidar measurements of

PROJECT SUMMARIES

aerosols during ACE-2: instrument description, results, and comparisons with other ground-based and airborne measurements," *Tellus*, 52B, pp. 636-651.

Johnson, D.W., Osborne, S., Wood, R., Suhre, K., Johnson, R., Businger, S., Quinn, P.K., Wiedensohler, A., Durkee, P.A., Russell, L.M., Andreae, M.O., O'Dowd, C., Noone, K.J., Bandy, B., Rudolph, J., and Rapsomanikis, S., "An overview of the Lagrangian experiments undertaken during the North Atlantic Regional Aerosol Characterization Experiment (ACE-2)," *Tellus*, 52B, pp. 290-320.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEY WORDS: Satellite Remote Sensing, Aerosol, Climatology

CLOUD PROPERTIES FOR ICE ANALYSIS USING MODIS DATA

Philip A. Durkee, Professor

Department of Meteorology

Sponsor: Naval Research Laboratory

OBJECTIVE: Test and optimize the NASA cloud mask for the MODIS instrument on the TERRA satellite.

SUMMARY: With the reduction of funding for sea ice reconnaissance flights, the National/Naval Ice Center needs to capitalize on the improvements in satellite technology. Imaging sensors such as AVHRR, DMSP/OLS, SSM/I and RADARSAT are used to detect the presence of sea ice, but with the exception of SSM/I and RADARSAT, clouds are a major obstacle to viewing the surface. With NASA's development of the Moderate-resolution Imaging Spectroradiometer (MODIS) and MODIS Airborne Simulator (MAS), there is finally a sensor capable of using multi-spectral techniques to detect the presence of clouds.

A group at the Space Science and Engineering Center (SSEC), University of Wisconsin-Madison lead by Dr. Steve Ackerman has developed a cloud mask for MAS/MODIS. The technique determines a level of confidence that a given pixel is clear based on a series of multi-spectral tests. By combining the confidence level from all tests, it is possible to detect the presence of clouds at different altitudes in the atmosphere. Threshold optimizations are described in this thesis for the $T_B(11\mu\text{m})$ and $T_B(3.9\mu\text{m}) - T_B(11\mu\text{m})$ tests from Ackerman et al. (1997). In addition, the $T_B(11\mu\text{m}) - T_B(12\mu\text{m})$ test is removed. These modifications are based on daytime analysis of several MAS cases and a limited number of MODIS cases.

Subjective analysis shows the modifications greatly improve the detection of clouds over cold polar oceans where sub-pixel ice may be present or water temperatures might falsely indicate clouds. The number of Cloudy pixels (≤ 0.66 clear confidence level) for a given scene was increased 12.1% on average for MAS cases. The NPS cloud mask also classified two times more Probably Clear and Undecided pixels than the original mask due to greater sensitivity to thin, small clouds.

THESIS DIRECTED:

Memmen, S.P., "Optimization of MAS and MODIS Polar Ocean Cloud Mask," Masters Thesis, Naval Postgraduate School, June 2000.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEY WORDS: Satellite, Remote Sensing, Clouds, Sea-Ice

PROJECT SUMMARIES

METOC DATA ASSIMILATION AND MODELING

Philip A. Durkee, Professor

Department of Meteorology

Sponsor: Space and Naval Warfare Systems Center-San Diego

OBJECTIVE: Develop atmospheric and oceanic analysis using satellite-measured radiance.

SUMMARY: This project produced verification and validation of the Satellite Marine-layer/Evaporation Duct Height (SMDH) technique under development by NAWC Point Mugu, California. The technique provides an estimate of the cloud-top height of stratocumulus clouds in the marine boundary layer for the area viewed by a polar orbiting weather satellite. The top of the marine boundary layer is the optimum coupling height for elevated ducts. Knowledge of the elevated duct height over the tactical battlespace is quite important. The SMDH technique is one component of a potential shipboard operational system to provide estimates of elevated duct height. The SMDH technique is verified using NOAA AVHRR satellite data and coincident rawinsonde or aircraft measurements from the 1987 FIRE and 1994 MAST data sets.

THESIS DIRECTED:

McBride, M.B., III, "Estimation of Stratocumulus-Topped Boundary Layer Depth Using Sea Surface and Remotely Sensed Cloud-Top Temperatures," Masters Thesis, Naval Postgraduate School, June 2000.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEY WORDS: Satellite, Remote Sensing, Clouds

USING THE SHEBA FLUX DATA TO IMPROVE REGIONAL AND GLOBAL CLIMATE MODELS

Peter Guest, Research Associate Professor

Department of Meteorology

Sponsor: National Science Foundation

OBJECTIVES: This is a collaborative effort to use the atmospheric surface layer data collected during the Surface Heat Budget of the Arctic field program to develop a state-of-the-art one-dimensional ice-atmosphere model of the Arctic. A longer-term objective is to improve forecasts of future global climate change.

SUMMARY: This continues an analysis of data collected during a field program that was performed from September 1997 to September 1998. The data set obtained represents the most comprehensive information on surface-layer properties ever obtained in the central Arctic. The project involves analysis of factors affecting the surface heat and momentum fluxes, including snow drifting, melting of the ice surface, radiation and cloud effects and the effects of nearby leads. These results will be incorporated into various models that simulate Arctic air-ice-sea interactions and their effects on regional and global climate.

PUBLICATIONS:

Andreas, E.L., Guest, P.S., Persson, O.P.G., Fairall, C.W., Horst, T.W., Moritz, R.E., and Semmer, S.R., 2001: Near-surface water vapor over polar sea ice is always near saturation, *Journal of Geophysical Research-Oceans*, in press.

Curry, J.A., Schramm, J.L., Alam, A., Reeder, R., Arbetter, T.E., and Guest, P. S., 2001: Evaluation of data sets used to force sea ice models in the Arctic Ocean, *Journal of Geophysical Research-Oceans*, in press.

Persson, O.P.G., Fairall, C.W., Andreas, E.L., Guest, P.S., and Perovich, D.K., 2001: Measurements near the Atmospheric Surface Flux Group tower at SHEBA Part I: Site description, data processing, and accuracy estimates, *Journal of Geophysical Research-Oceans*, in press.

PROJECT SUMMARIES

Persson, O.P.G., Fairall, C.W., Andreas, E.L., and Guest, P.S., 2001: Measurements near the Atmospheric Surface Flux Group tower at SHEBA Part I: Near-surface conditions and surface energy budget, *Journal of Geophysical Research-Oceans*, in press.

PRESENTATIONS:

Guest, P.S., Persson, O.P.G., Andreas, E.L., and Fairall, C.W., 2001: What is the role of the sensible heat flux on the surface heat budget of the multi-year sea ice?, Sixth Conference on Polar Meteorology and Oceanography, 14-18 May 2001, San Diego, CA.

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Andreas, E.L., Guest, P.S., Persson, O.P.G., Fairall, C.W., Horst, T.W., and Moritz, R.E., 2001: Relative humidity measurements near saturation at temperatures well below 0°C, *Preprint Volume, 11th Symposium on Meteorological Observations and Instrumentation of the American Meteorological Society*, Albuquerque, NM, 14-18 January 2001, pp. 159-164, (Program in American Meteorological Society, 81, pp. 2848-2855).

Fairall, C.W., Intrieri, J.M., Shupe, M., Guest, P.S., Andreas, E.L., and Persson, O.P.G., 2001: Cloud forcing of turbulent and radiative energy budgets on the Arctic ice cap: one year of data from the SHEBA experiment, Sixth Conference on Polar Meteorology and Oceanography, 14-18 May 2001, San Diego, CA.

Persson, O.P.G., Fairall, C.W., Andreas, E.L., and Guest, P.S., 2001: Measurements of the surface energy budget on multi-year ice at SHEBA, Sixth Conference on Polar Meteorology and Oceanography, 14-18 May 2001, San Diego, CA.

DoD KEY TECHNOLOGY AREAS: Environmental Quality, Other (Meteorology)

KEYWORDS: Polar Meteorology, Air-Sea-Ice Interactions, Surface Fluxes, Arctic Surface Heat Budget, Air-Ice Interaction, SHEBA

EVOLUTION OF TROPICAL CYCLONE CHARACTERISTICS

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Elizabeth A. Ritchie, Research Assistant Professor
Russell L. Elsberry, Distinguished Professor
Department of Meteorology
Sponsor: Office of Naval Research

OBJECTIVE: Tropical cyclone frequency, motion, and structure characteristics depend on a variety of environmental and internal factors. The primary objectives of this research are to identify these factors and determine how each impacts tropical cyclone characteristics.

SUMMARY: It is hypothesized that mechanisms responsible for clustering of tropical cyclone activity can be put into a framework of external and internal forcing. A wavelet analysis of the circulation patterns over the Indian Ocean/western Pacific regions has been used to define spatial variability in various frequency bands that can be related to external and internal influences on tropical cyclone activity. External modes vary over time scales between 10-60 days while internal modes vary over synoptic time scales. A singular-value decomposition of circulation and convection fields related to the time-frequency specified external and internal modes defined spatial patterns associated with each mode. During periods of high amplitude external modes, a modulation of the synoptic-scale features exists such that enhanced easterly (westerly) vertical wind shear is associated with enhanced (reduced) synoptic-scale activity. However, considerable variability in the structural characteristics and amplitude of the external modes is causes uncertainty in the

PROJECT SUMMARIES

modulation of synoptic-scale features. Therefore, the key to defining potential initiation of intraseasonal periods of tropical cyclone activity or inactivity is identification of the variability in the principal features of the external modes that influence the synoptic scale directly.

The structural evolution of a tropical cyclone to an extratropical cyclone has been defined to occur in two stages, transformation and re-intensification. It is hypothesized that the development of the extratropical cyclone during re-intensification depends on the phasing of the pole ward-moving tropical cyclone and a critical region in the mid-latitude circulation that contains essential elements for support of extra tropical cyclogenesis. The sensitivity of re-intensification to the phasing between the tropical cyclone and the midlatitude circulation into which the tropical cyclone is moving has been examined by numerical experimentation with a high-resolution mesoscale numerical model. The movement of the tropical cyclone into the midlatitudes was delayed or accelerated to examine the relative roles of tropical and midlatitude features on re-intensification. Favorable phasing between the tropical cyclone and midlatitude circulation resulted in both baroclinic and barotropic conversion of potential energy to kinetic energy, which favored re-intensification as an extratropical cyclone. Unfavorable phasing resulted in the destruction of kinetic energy and failure to re-intensify as an extra tropical cyclone.

PUBLICATIONS:

Harr, P.A. and Elsberry, R.L., 2000: Extratropical transition of tropical cyclones over the western North Pacific, Part I: Evolution of structural characteristics during the transition process, *Monthly Weather Review*, 128, pp. 2613-2633.

Harr, P.A., Elsberry, R.L., and Hogan, T.F., 2000: Extratropical transition of tropical cyclones over the western North Pacific, Part II: Impact of midlatitude circulation characteristics, *Monthly Weather Review*, 128, pp. 2634-2653.

Klein, P.M., Harr, P.A., and Elsberry, R.L., 2000: Extratropical transition of western North Pacific tropical cyclones: An overview and conceptual model of the transformation stage, *Weather and Forecasting*, 15, pp. 373-395.

PRESENTATIONS:

Harr, P.A., Elsberry, R.L., and Chan, J.C.L., 2000: Forecasts of intraseasonal periods of tropical cyclone inactivity over the tropical western North Pacific, Twenty-fourth Conference on Hurricanes and Tropical Meteorology, Ft. Lauderdale, FL, American Meteorological Society, pp. 51-52.

Klein, P.M., Harr, P.A., and Elsberry, R.L., 2000: Extratropical transition in the western North Pacific: Demonstration of the importance of phasing with the midlatitude circulation pattern during the re-intensification stage, Twenty-fourth Conference on Hurricanes and Tropical Meteorology, Ft. Lauderdale, FL, American Meteorological Society, pp. 316-317.

Harr, P.A., Elsberry, R.L., and Klein, P.M., 2000: An overview of extratropical transition over the western North Pacific, Invited Presentation, Eleventh Cyclone Workshop, Pacific Grove, CA, 27 August-1 September 2000.

OTHER:

Chang, C.P., Harr, P.A., and Ju, J., 2000: Possible roles of Atlantic circulations on the weakening Indian monsoon rainfall-ENSO Relationship, *Journal of Climate*, in press.

Klein, P.M., Harr, P.A., and Elsberry, R.L., 2000: Extratropical transition of western North Pacific tropical cyclones: Midlatitude and tropical cyclone contributions to re-intensification, to be submitted to *Monthly Weather Review*.

PROJECT SUMMARIES

DoD TECHNOLOGY AREAS: Environmental Quality, Modeling and Simulation

KEYWORDS: Tropical Cyclones, Midlatitude Cyclones, Numerical Weather Prediction, Extratropical Transition

NUMERICAL HINDCASTS OF THE CALIFORNIA CURRENT

Robert L. Haney, Professor
Department of Meteorology
Sponsor: Office of Naval Research

OBJECTIVE: The broad objective of this research is to aid in the development of a reliable modeling capability for eastern boundary current regions.

SUMMARY: The numerical simulations and hindcasts of the California Current are being carried out using the DieCAST regional model. The numerical simulations have been forced by monthly climatological winds, while the hindcasts will be driven by a two-year data set of high resolution wind fields produced by quasi-operational atmospheric prediction models, the MM5 and COAMPS models, respectively. The verifications will make use of data from ONR's CTZ and EBC programs (for statistical and phenomenological verifications) and TOPEX/Poseidon altimeter data (for hindcast behavior). During the last year we completed three diagnostic studies, two in the California Current (Haney and Hale 2001; Shearman *et al* 2000), and one in the Alboran Sea (Viudez *et al.* 2000). We also completed a simulation study of the California Current (Haney *et al.* 2001). Work has also progressed to access the surface wind stress from MM5 model runs from October 1998 to October 2000. This wind stress data, along with similar data from the COAMPS reanalysis fields that are being prepared by J. Kindle (Stennis Space Center), will be used to force the ocean model during the two-year hindcasts.

PUBLICATIONS:

Shearman, R.K., Barth, J.A., Allen, J.S., and Haney, R.L., 2000: Diagnosis of the three-dimensional circulation in mesoscale features with large Rossby number, *Journal of Physical Oceanography*, 30, pp. 2687-2709.

Viudez, A., Haney, R.L., and Allen, J.T., 2000: A study of the balance of horizontal momentum in a vertical shearing current, *Journal of Physical Oceanography*, 30, pp. 572-589.

Haney, R.L. and Hale, R.A., 2001: The use of digital filter initialization to diagnose the mesoscale circulation and vertical motion in the California coastal transition zone, *Journal of Marine Systems*, in press.

Haney, R.L., Hale, R.A., and Dietrich, D.E., 2001: Offshore propagation of eddy kinetic energy in the California Current, *Journal of Geophysical Research*, in press.

PRESENTATION:

Haney, R.L., Hale, R.A., and Dietrich, D.E., 2000: Offshore propagation of eddy kinetic energy in the California Current, presented at the European Geophysical Society XXV General Assembly, Nice, France, 25-29 April 2000.

DoD KEY TECHNOLOGY AREAS: Other (Physical Oceanography)

KEYWORDS: Numerical Ocean Modeling, Coastal Oceanography, California Current

PROJECT SUMMARIES

DECADAL TELECONNECTIONS IN THE NORTH PACIFIC AND GLOBEC - NORTHEAST PACIFIC CLIMATE CHANGE MECHANISMS

Tom Murphree, Senior Lecturer

Department of Meteorology

Sponsor: National Oceanic and Atmospheric Administration

OBJECTIVE: This project is designed to analyze climatic variations of the North Pacific – North American atmosphere and ocean, and the mechanisms that produce these variations.

SUMMARY: These two projects are part of the U.S. GLOBEC research program, funded by the National Science Foundation and the National Oceanic and Atmospheric Administration (NOAA). These projects are being conducted in collaboration with researchers in the Department of Oceanography at the Naval Postgraduate School (NPS) and at the Pacific Fisheries Environmental Laboratory (PFEL) of NOAA in Pacific Grove, CA. Our goal is to develop a better understanding of the intraseasonal to decadal variations of the atmosphere and ocean in the North Pacific – North American (NPNA) region. Our work emphasizes the identification and description of the mechanisms that govern these variations (e.g., teleconnections from remote regions and their impacts on surface wind stress and moisture transports). This research involves dynamical analyses of observed, analyzed, and modeled atmospheric and oceanic fields. During 2000, our focus was on: (1) additional development and application of the Northern Oscillation Index (NOI), a new index of climate variability in the NPNA region; (2) diagnostic analyses of interannual to decadal variations of upper ocean temperatures; (3) initial analyses of the simulation of these variations by a global ocean circulation model; and (4) identification of the major atmospheric and oceanic mechanisms that link the NPNA region to southern and eastern Asia and the tropical Pacific.

PUBLICATIONS:

Schwing, F.B., Murphree, T., deWitt, L., and Green, P.M., "The Evolution of Oceanic and Atmospheric Anomalies in the Northeast Pacific During the El Niño and La Niña Events of 1995-2000," *Progress in Oceanography*, in press.

Schwing, F.B., Murphree, T., and Green, P.M., "A Climate Index for the Northeast Pacific," *Progress in Oceanography*, in press.

Murphree, T. and Schwing, F., "Long Term Variations of the Northeast Pacific," *Ecosystems Observations*, 2000, pp. 22-24.

Murphree, T., Feinberg, L., Schwing, F.B., and Smith, R., "Decadal Climate Events in the Northeast Pacific," Report from the Northeast Pacific Global Ecosystems Dynamics Workshop, Corvallis, OR, November 2000.

CONFERENCE PRESENTATIONS:

Green, P., Schwing, F., and Murphree, T., "Wind Stress Curl and Ocean Conditions in the Northeast Pacific: A Mechanism for Ocean Climate Change," 47th Annual Eastern Pacific Ocean Conference, Sidney, British Columbia, Canada, September 2000.

Green, P., Schwing, F., and Murphree, T., "The Extratropical Northern Oscillation Index: A New Index of Environmental Variability for the Northeast Pacific," 17th Annual PACLIM Workshop, Santa Catalina Island, CA, May 2000.

Green, P., Schwing, F., and Murphree, T., "Climate Change in the Monterey Bay National Marine Sanctuary Based on the Extratropical NOIX," 17th Annual PACLIM Workshop, Santa Catalina Island, CA, May 2000.

Murphree, T., Schwing, F., and Green, P., "Climatic Regimes of the Northeast Pacific," 2000 Ocean Sciences Meeting, San Antonio, TX, January 2000.

PROJECT SUMMARIES

Murphree, T., Schwing, F., Green, P., Tokmakian, R., Mendelssohn, R., deWitt, L., Semtner, B., Ford, B., Moore, C., and Parrish, R., "Northeast Pacific Climate Change Mechanisms," Northeast Pacific Global Ecosystems Dynamics Workshop, Corvallis, OR, November 2000.

Mendelssohn, R., Schwing, F., and Murphree, T., "Interannual Variations in the Seasonal Behavior of the Northeast Pacific," 2000 Ocean Sciences Meeting, San Antonio, TX, January 2000.

Schwing, F.B., Murphree, T., and Mendelssohn, R., "Dynamic Similarity of Climate Events: Using the Mechanisms of El Niño as a Model for Regime Shifts and Climate Change," Beyond El Niño: A Conference on Climate Variability and Marine Ecosystem Impacts, from the Tropics to the Arctic, La Jolla, CA, March 2000.

Schwing, F.B., Green, P.M., and Murphree, T., "An Analysis of El Niño, La Niña, and Other Climate Events in the Northeast Pacific Based on the Extratropical Northern Oscillation Index," Ocean Sciences Meeting, San Antonio, TX, January 2000.

DoD KEY TECHNOLOGY AREAS: Environmental Quality, Other (Environmental Processes, Environmental Monitoring, Environmental Modeling)

KEYWORDS: Atmospheric and Oceanic Variations, El Niño, GLOBEC, La Niña, North Pacific, Teleconnections, Weather and Climate System

EVOLUTION OF LOW-LEVEL FLOW PATTERNS IN LITTORAL REGIONS WHEN EXTRATROPIC CYCLONES ENCOUNTER COASTAL MOUNTAINS

Wendell A. Nuss, Associate Professor

Douglas K. Miller, Research Assistant Professor

Department of Meteorology

Sponsor: Office of Naval Research

OBJECTIVE: The objective of this project is to utilize observations collected during the California Land-falling Jets Experiment (CALJET) to examine the interaction of land-falling cyclones with coastal topography. Specifically the tendency of the low-level wind sheltering and enhancement by coastal topography will be diagnosed using a mesoscale analysis system applied to CALJET data. These analyses will be used to assess the temporal and spatial aspects of the flow interaction as well as to validate mesoscale model forecasts of this phenomena.

SUMMARY: Synoptic-scale analyses from NOGAPS have been used to characterize the incident flow through the CALJET period as it interacts with the California coastline near Monterey. This synoptic characterization has been used to determine the flow direction, speed, and stratification for multiple events during the winter of 1998. Mesoscale observations for the Monterey Bay region have been assembled for these cases in order to perform mesoscale analyses to characterize the flow response to topography. The three dimensional multiquadric analysis code has been completed and thoroughly tested in order to complete these analyses. This analysis code is being used routinely to produce local mesoscale analyses in real time. These are available on the web at http://www.weather.nps.navy.mil/wx/latest_anal.html and are being used to routinely characterize the mesoscale circulations in the Monterey region. The primary results to date have been the development of reliable analysis software and the characterization of the synoptic-scale evolution of several events during the CALJET period. One case, Feb. 5, has been analyzed more completely and it shows evidence channeling and flow sheltering in the lee of topography. These effects seem to be time dependent as a front approaches with the most prevalent interaction occurring with increased pre-frontal stratification. The threshold for these effects is being determined for this case and will be extended to other cases to better apply basic theories of topographic flow interaction to arbitrary flows in complex topography. The analysis software to perform mesoscale analyses is working very well and routinely shows mesoscale eddies and other topographic effects in the real-time analyses for the Monterey Bay region. Application to the historical data for the CALJET period should provide adequate definition of

PROJECT SUMMARIES

flow interaction effects. Quality control of the mesoscale data has been partially completed and has been found to be essential to provide accurate mesoscale analyses.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Coastal Meteorology, Mesoscale Modeling, Regional Forecasting

CENTRAL CALIFORNIA MESONET FOR USE IN LAPS AND LOCAL MESOSCALE MODELING

Wendell A. Nuss, Associate Professor

Department of Meteorology

Sponsor: National Weather Service (COMET)

OBJECTIVE: The objective of this project is to develop a mesoscale observing network from existing sources and utilize these data in the Local Analysis and Prediction System (LAPS) at San Jose State University and real-time MM5 forecasts at the Naval Postgraduate School. The data will also be used to conduct model verifications and mesoscale circulation studies.

SUMMARY: Data from a variety of observing networks are being gathered by NPS to develop a California mesoscale observing network (mesonet). Presently observations from the California Department of Forestry, National Weather Service, and various NPS run stations are being collected in real-time with stations from local air pollution districts and the California Irrigation Management Service being collected once per day. These observations are being shared with San Jose State University and the National Weather Service as well as being used to produce a local mesoscale wind analysis that is displayed on the web (http://www.weather.nps.navy.mil/wx/latest_mbay.gif). The mesonet data is being utilized to feed into the real-time mesoscale model forecasts done by NPS. Additional observations from the California Department of Water Resources have been added and are being ingested into the mesonet.

PRESENTATION:

Nuss, W.A., 2000: Developing a California Mesonet, ALERT Users Group Meeting, Monterey CA, 1-4 May 2000.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Coastal Meteorology, Mesoscale Modeling, Regional Forecasting

DEPENDENCE OF MESOSCALE COASTAL PREDICTABILITY ON DATA ASSIMILATION AND DISTRIBUTION OF OBSERVATIONS

Wendell A. Nuss, Associate Professor

Douglas K. Miller, Research Assistant Professor

Department of Meteorology

Sponsor: Office of Naval Research

OBJECTIVE: The objectives of this research are to determine the ability to numerically predict mesoscale coastal structures in a variety of synoptic scale situations and demonstrate for given small-scale structures the time ranges under which they might be considered predictable. The answer is probably dependent on the data assimilation system and one objective is to determine this sensitivity.

SUMMARY: This study has utilized numerical model predictions of a winter case from the California Landfalling Jets Experiment (CALJET) and a summer case of a sea breeze event in the Monterey region to test the sensitivity of predictions to variations in the synoptic scale flow. Tests utilizing different samples of the synoptic scale structure to initiate mesoscale numerical model forecasts were done to assess the impact of synoptic scale variability on mesoscale error growth. Key results from this study by Kuypers

PROJECT SUMMARIES

(2000) show that mesoscale error growth is strongly controlled by the lateral boundary conditions and that mesoscale error is dominated by the synoptic scale error. Variations in the synoptic-scale structure caused by sampling differences were shown to contribute a rather large range in mesoscale forecasts. To better quantify this sensitivity to the large-scale structure, controlled experiments were done by rotating the topography 1 degree as a land-falling front interacted with the coastal mountains. The results of this study showed that very small variations in synoptic-scale flow direction were enough to produce large differences in mesoscale precipitation and winds. The physical mechanisms responsible for these variations were due to differing amplitudes in moist mountain waves excited by the topography. These results suggest that while topographic features can constrain the flow in some regimes, they can introduce significant variations in others rendering the mesoscale aspects of the flow to be weakly predictability.

PUBLICATION:

Nuss, W.A. and Miller, D.K., "Mesoscale Predictability Under Various Synoptic Regimes," *Nonlinear Processes in Geophysics*, 25.

PRESENTATIONS:

Nuss, W.A. and Miller, D.K., "Coastal orography: Does it help or harm mesoscale predictability? Invited presentation at Pacific Northwest Weather Workshop, Seattle, WA, 4-5 February 2000.

Nuss, W.A. and Miller, D.K., "Mesoscale predictability under various synoptic regimes," European Geophysical Society Meeting, Nice France, 23-29 April 2000.

Nuss, W.A. and Miller, D.K., "Sensitivity of frontal circulations to topographic forcing," 9th Conference on Mountain Meteorology, Aspen, CO, 7-11 August 2000.

Miller, D.K. and Nuss, W.A., "Forecast sensitivity of a CALJET cyclone to varied representations of orography," Extratropical Cyclone Workshop, Asilomar, Pacific Grove, CA, 28 August-1 September 2000.

Nuss, W.A., Miller, D.K., and Kuypers, M.A., "Impact of atmospheric synoptic-scale variability on mesoscale forecast error growth," American Geophysical Society Meeting, San Francisco, CA, 15-19 December 2000.

Nuss, W.A. and Miller, D.K., "Model predictability of quantitative precipitation in a land falling front," American Geophysical Society Meeting, San Francisco, CA, 15-19 December 2000.

THESIS DIRECTED:

Kuypers, M., "Understanding Mesoscale Error Growth and Predictability," Masters Thesis, Naval Postgraduate School, June 2000.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Data Assimilation, Predictability, Regional Forecasting

TROPICAL CYCLONE STRUCTURE CHANGES

Elizabeth A. Ritchie, Research Assistant Professor

Russell L. Elsberry, Distinguished Professor

Department of Meteorology

Sponsor: Office of Naval Research

OBJECTIVES: The objective of this portion of the continuing project is to study the impact of structural changes on the subsequent motion and intensity of tropical cyclones using the Navy's coupled ocean atmosphere mesoscale prediction system (COAMPS).

PROJECT SUMMARIES

SUMMARY: Track changes of tropical cyclones due to interaction with a nearby mesoscale convective system were studied using COAMPS (Ritchie and Elsberry 2000a). Tropical cyclone structural changes that develop as a tropical cyclone transitions to an extratropical cyclone were studied using COAMPS as part of an ongoing project to better understand extratropical transition (Ritchie and Elsberry 2001; 2000b). The physical mechanisms that result in tropical cyclone formation were studied using remote-sensing instruments as part of a collaborative project with NASA (Ritchie 2000).

PUBLICATIONS:

Ritchie, E.A. and Elsberry, R.L., 2001: Simulations of the transformation stage of the extratropical transition of tropical cyclones, *Monthly Weather Review*, in press.

Ritchie, E.A., 2000: Some aspects of midlevel vortex dynamics in tropical cyclogenesis, *Minutes of the 54th Interdepartmental Hurricane Conference*, Office of the Federal Coordinator for Meteorological Services and Supporting Research, Silver Spring, MD, pp. A166-A171.

Ritchie, E.A. and R.L. Elsberry, 2000a: Simulated impacts of a mesoscale convective system on the track of Typhoon Robyn during TCM-93, *Monthly Weather Review*, 128, pp. 2232-2251.

Ritchie, E.A. and Elsberry, R.L., 2000b: Simulations of the Transformation Stage of the extratropical Transition of Tropical Cyclones, *Proceedings of the 24th Conference on Hurricanes and Tropical Meteorology*, American Meteorological Society, Boston, MA, pp. 322-323.

PRESENTATIONS:

Elsberry, R.L., Hirschberg, P.A., Shafran, P.C., and Ritchie, E.A., 2000: An observing system experiment with the West coast picket fence during STORM-FEST, The 2nd USWRP Science Symposium, 27-28 March 2000, Boulder, CO.

Ritchie, E.A., 2000: Some aspects of midlevel vortex dynamics in tropical cyclogenesis, The 54th Interdepartmental Hurricane Conference, 14-18 February 2000, Houston, TX.

Ritchie, E.A. and Elsberry, R.L., 2000a: Simulations of the Transformation Stage of the extratropical Transition of Tropical Cyclones, The 24th Conference on Hurricanes and Tropical Meteorology, 29 May - 2 June 2000, Ft. Lauderdale, FL.

Ritchie, E.A. and Elsberry, R.L., 2000b: Simulations of the Extratropical Transition of Tropical Cyclones, The 11th Cyclone Workshop, 27 August-1 September 2000, Pacific Grove, CA.

Ritchie, E.A., Simpson, J., Pierce, H., Brueske, K., and Velden, C., 2000: On the Genesis of Tropical Cyclones: Role of mesoscale interactions, American Geophysical Union, 2000 Fall Meeting, 81, 15-19 December 2000.

OTHER:

Hirschberg, P.A., Shafran, P.C., Elsberry, R.L., and Ritchie, E. A., 2000: An observing system experiment with the West coast picket fence, *Monthly Weather Review*, in review.

Ritchie, E.A., 2000: Some aspects of midlevel vortex interaction in tropical cyclogenesis, *Meteorology Monograph*, in review.

Ritchie, E.A., Simpson, J., Pierce, H., Brueske, K., and Velden, C., 2000: On the Genesis of Tropical Cyclones: Role of mesoscale interactions, American Geophysical Union, Book Chapter, Historical Symposium on Hurricanes, in progress.

PROJECT SUMMARIES

DoD TECHNOLOGY AREAS: Environmental Quality, Modeling and Simulation, Other (Meteorology)

KEYWORDS: Tropical Cyclones, Mesoscale Modeling

MECHANISMS FOR RAPID INTENSITY CHANGES IN HURRICANES

Elizabeth A. Ritchie, Research Assistant Professor

Department of Meteorology

William M. Frank, Professor

Pennsylvania State University

Sponsor: National Science Foundation

OBJECTIVES: The objective of this project is to investigate mechanisms for rapid intensity changes in hurricanes through high-resolution, mesoscale modeling.

SUMMARY: The impact of vertical shear on tropical cyclone structure and intensity was studied using higher-resolution (5-km) simulations (Frank and Ritchie 2000; 2001). Realistic Atlantic-basin environmental regimes were successfully simulated using the higher-resolution configuration of the model. In addition, the detailed structural changes produced by asymmetric convection in the core of tropical cyclones were investigated.

PUBLICATION:

Frank, W.M. and Ritchie, E.A., 2000: Effects of vertical wind shear on the structure and intensity of hurricanes, *Proceedings of the 24th Conference on Hurricanes and Tropical Meteorology*, American Meteorological Society, Boston, MA, 5-6.

PRESENTATIONS:

Frank, W.M. and Ritchie, E.A., 2001: Mechanisms for rapid intensity changes in hurricanes, The 3rd USWRP Science Symposium, Orlando, FL, 5-9 March 2000.

Frank, W.M. and Ritchie, E.A., 2000: Effects of vertical wind shear on the structure and intensity of hurricanes, The 24th Conference on Hurricanes and Tropical Meteorology, Ft. Lauderdale, FL, 29 May-2 June 2000.

OTHER:

Frank, W.M. and Ritchie, E.A., 2001: Effects of Vertical Wind Shear on Hurricane Intensity and Structure, *Monthly Weather Review*, in review.

Ritchie, E.A. and Frank, W.M., 2001: Effects of Vertical Wind Shear on Tropical Cyclone Intensity and Structure: Directional and Cross-Track Shear, *Monthly Weather Review*, in progress.

Ritchie, E.A. and Frank, W.M., 2001: Effects of long-lived convective asymmetries on tropical cyclone structure change, *Monthly Weather Review*, in progress.

DoD TECHNOLOGY AREAS: Environmental Quality, Modeling and Simulation, Other (Meteorology)

KEYWORDS: Tropical Cyclones, Mesoscale Modeling

PROJECT SUMMARIES

AIRCRAFT MEASUREMENTS AND ANALYSES OF THE CLOUDY BOUNDARY LAYERS AND TURBULENCE IN THE ARCTIC

Qing Wang, Assistant Professor
Department of Meteorology

Sponsor: National Aeronautics and Space Administration-Langley

OBJECTIVE: The objective of this project is to understand the inhomogeneity in the Arctic boundary layer as a result of low-level clouds and the differences in turbulence structure under clear and stable conditions. The goal is to understand the role of stratocumulus clouds in the Arctic climate system. The study is part of the effort of FIRE-III/SHEBA.

SUMMARY: Aircraft measurements on boundary layer turbulence structure were made by the NCAR C-130 during the Beaufort Arctic Storms Experiment (BASE) in 1994. Data from one flight during the BASE experiment have been analyzed to study the boundary layer inhomogeneity introduced by the presence of low-level clouds and the fractional cloud cover. It was found that the boundary layer thermodynamics were largely determined by the cloud-top height, since the presence of cloud generally resulted in one or two mixed layers below the cloud top. The two-mixed layer structure in some of the soundings is the result of multiple cloud layers, which is different from the decoupled boundary layers in the subtropical marine boundary layers. In addition, the presence of low-level cloud significantly increased the intensity of boundary layer turbulence. However, we did not observe significant increase in the magnitude of surface flux in cloudy region compared to the clear region. Further study indicated that the small flux is caused by the small temperature or moisture perturbation. The turbulence spectra in the clear and cloudy regions indicated that the cloud layer alters the turbulence spectra significantly.

OTHER:

Wang, S., Wang, Q., Jordan, R., and Persson, O. P. G., 2000: Interaction among longwave radiation of cloud, turbulence, and snow surface temperature: model sensitivity study, accepted by *Journal of Geophysical Research*.

Wang, Q. and Wang, S., 2001: Cloud and turbulence in the Arctic Autumnal boundary layers, to be submitted to *Boundary Layer Meteorology*.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Boundary Layer Meteorology, Turbulence Structure, Arctic Research

EVALUATIONS OF SURFACE FLUX AND BOUNDARY PARAMETERIZATIONS IN COAMPS USING AIRCRAFT MEASUREMENTS

Qing Wang, Assistant Professor
Department of Meteorology
Sponsor: Office of Naval Research

OBJECTIVE: The objective of this project is to evaluate the surface flux and boundary layer parameterizations currently used in COAMPS using measurements from Japan/East Sea Experiment (JES).

SUMMARY: It is generally understood that boundary layer parameterization and surface flux parameterization interact nonlinearly in a mesoscale model. The atmospheric forcing to the ocean is thus affected by the boundary layer parameterizations even with perfect formulation of the drag and exchange coefficients. However, such effect has not been quantified. This project intends to evaluate the behavior of the model predicted boundary layer and surface flux in order to improve the model representation of the lower atmosphere, particularly the surface fluxes. We have setup simulations using COAMPS for the Japan/East Sea region at NPS. Initial simulation for one case in JES suggested strong sensitivity of surface fluxes to parameters in boundary layer parameterizations. We found from two controlled simulations where different formulations of mixing length were used that the surface sensible and latent heat fluxes

PROJECT SUMMARIES

were different by nearly 40% in some regions, although the simulated boundary layer heights are similar. We also found that the boundary layer properties are rather sensitive to the use of roughness length formulations with the same surface flux parameterization. Our results suggested the need to evaluate all components of the atmospheric boundary layer including both surface flux parameterization and boundary layer parameterization in order to obtain appropriate atmospheric forcing of the ocean. Our results also indicated that the evaluation of the modeled boundary layer could not be achieved by simple comparison of one or two boundary layer properties with observations. It requires comprehensive understanding of both the observed boundary layer and the model boundary layers through systematic analysis on both sides.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Surface Flux, Boundary Layer Parameterization, COAMPS, Aircraft Measurement

UNDERSTANDING THE EVOLUTION OF STRATOCUMULUS CLOUDS IN THE COASTAL ZONE

Qing Wang, Assistant Professor

Department of Meteorology

Sponsor: National Science Foundation

OBJECTIVE: The objective of this project is to examine the physical processes affecting the evolution of coastal stratocumulus clouds.

SUMMARY: The stratocumulus cloud/fog in the coastal region is different from that over the open water where the large scale forcing is relatively well defined and there is considerable horizontal homogeneity. In order to improve the forecast of coastal stratocumulus clouds, one has to understand the interaction among the clouds, the coastal mesoscale circulation, and the effects of land surfaces on cloud evolution. Field measurements of the coastal stratocumulus and the associated boundary layer were made off the coast of Monterey using the CIRPAS Twin Otter research aircraft. The aircraft was newly equipped with instruments for turbulence measurements in the Atmospheric Boundary Layer. A calibration of the instruments and a preliminary analysis of the corrected data have been performed. The main effort of the calibration involved the radome-nose pressure probe and the pitot/static tube on the fuselage near the aircraft nose. These sensors and GPS velocity and attitude measurements are used to estimate wind turbulence. A significant impact of the acceleration of the aircraft (propellers' direct and indirect-lift induced effect) on the calibration of the static/dynamic pressure and the attack angle was found and included in the calibration of the turbulence system.

In the stratocumulus related efforts, we also performed intensive analysis of the layered structure of the stratocumulus-topped boundary layers, inversion structure, and the convective activities within the cloudy boundary layers.

PUBLICATIONS:

Wang, Q. and McDowell, D.W., 2000: Entrainment drying of the stratocumulus-topped boundary layer, *Proceedings of the 14th Symposium on Boundary layers and Turbulence*, American Meteorological Society, 7-11 August 2000, Aspen, CO, pp. 76-79.

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PROJECT SUMMARIES

International Association of Meteorology and Atmospheric Physics, 14-18 August 2000, Reno, NV, Vol. 2, pp. 819-822.

OTHER:

Wang, Q. and McDowell, D.W., 2000: Entrainment and layered structure above the stratocumulus cloud top, in revision for *Journal of Atmospheric Sciences*.

Kalogiros, J.A. and Wang, Q., 2001: Wind turbulence measurements in the Atmospheric Boundary Layer using a radome-differential GPS system on a small research aircraft, under revision in the *Journal of Atmospheric and Oceanic Technology*.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Coastal Clouds, Boundary Layer Evolution, Aircraft Turbulence Measurement

ENTRAINMENT AND LAYERED STRUCTURE ABOVE THE STRATOCUMULUS CLOUD TOP

Qing Wang, Assistant Professor

Department of Meteorology

Sponsor: National Science Foundation

OBJECTIVE: The objective of this study is to understand the layered structure observed above the stratocumulus-topped boundary layer.

SUMMARY: It is known that entrainment at the boundary layer top results in the growth of the boundary layer in cloud free conditions. This concept has been adapted to the stratocumulus-topped boundary layer even though the physical processes involved are much more complex. The results in this study suggest that the presence of the cloud layer indeed may modify the effects of entrainment through evaporation of the cloud droplets and cloud-top radiative cooling, which are processes not present in the cloud free cases. From multiple soundings we found layered structure within one or two hundred meters above the stratocumulus top. Analysis of the coherent signal within each layer and the presence of turbulence and cloud droplets suggest that the layers were part of the boundary layer in its history of evolution. We formed a conceptual model that describes the formation of the layered structure as the result of entrainment mixing and the subsequent evaporation of the cloud droplets in the mixture of inversion air and the boundary layer air. The observed properties of the layers above the cloud support the hypothesis in the conceptual model.

The findings in this study suggest the importance of droplet evaporation related to cloud-top entrainment and of radiative cooling and turbulence mixing in establishing a new interface at the cloud top. The role of entrainment thus can be very different from that in the clear boundary layer. The cause of the entrainment drying of the cloud layer may have to do with the time scale of boundary layer turbulence mixing and the time scale of entrainment mixing, which are subjects requiring further investigation.

PUBLICATIONS:

Wang, Q. and McDowell, D.W., 2000: Entrainment and layered structure above the stratocumulus cloud top, in revision for *Journal of Atmospheric Science*.

Wang, Q. and McDowell, D.W., 2000: Entrainment drying of the stratocumulus-topped boundary layer, *Proceedings of the 14th Symposium on Boundary Layers and Turbulence*, American Meteorological Society, 7-11 August 2000, Aspen, CO, pp. 76-79.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Boundary Layer Measurements, Cloud-Top Entrainment

PROJECT SUMMARIES

NUMERICAL MODELING OF TURBULENCE-AEROSOL-CLOUD INTERACTION

Qing Wang, Assistant Professor
Department of Meteorology
Sponsor: Naval Research Laboratory

OBJECTIVE: The objective for this project is to understand the interaction between turbulence, atmospheric aerosols, and marine stratocumulus clouds.

SUMMARY: This study is a modeling effort to address the indirect radiative effect of aerosol, i.e., its interaction with low-level clouds. Results from past 1-D models with explicit aerosol and cloud microphysics have shown significant discrepancies from results from large eddy simulations and/or observations. This was caused by unrealistic representation of aerosol activation and droplet growth processes. In 2000, through numerous testing, we are now implementing new schemes to account for the turbulence-cloud microphysics interaction on the mean quantities. The results from our current model are very encouraging.

Meanwhile, we tried to understand the turbulence-cloud microphysics interaction using other types of models including higher order turbulence closure model with parameterized cloud droplet spectra and a large eddy simulation model with size-resolved cloud microphysics.

PUBLICATION:

Wang, S. and Wang, Q., 2000: A cloud microphysical parameterization for higher-order turbulence closure Models, *Proceedings of the 13th International Conference on Clouds and Precipitation*, International Commission on Clouds and Precipitation, International Association of Meteorology and Atmospheric Physics, 14-18 August 2000, Reno, NV, Vol. 1, 557-560.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Boundary Layer Modeling, Aerosol-Cloud Interaction

COLLABORATIVE RESEARCH PROJECTS IN DIRECT SUPPORT OF FNMOC

OPERATIONAL MISSION
Carlyle H. Wash, Professor
Department of Meteorology
Sponsor: Office of Naval Research

OBJECTIVE: The board objective of this research is to execute collaborative research projects with the Fleet Numerical Meteorology and Oceanography Center (FNMOC). The collaboration includes NPS Meteorology faculty, NPS students conducting thesis research, and FNMOC personnel. These joint projects address FNMOC operational needs and advance the understanding of marine meteorology.

SUMMARY: Two collaborative thesis projects were supported in FY00 funding. The first project was: Improvements to METOC Analysis and Forecast Visualizations by LT Keith Barto. NPS thesis advisor was Professor C. H. Wash and FNMOC collaborator was Mr. Ralph Loveless. In this study, LT Barto incorporated high resolution (1 km) global topography data base into Joint METOC Viewer (released as version 3.4) and other FNMOC model and data displays.

The second project is: The Role of Weather in Class A Naval Aviation Mishaps FY90-98 by LCDR Ruben Cantu. NPS thesis advisors were Professor C. H. Wash and Senior Lecturer Tom Murphree. In this study, 235 Class A Navy and Marine aviation mishaps involving aircrew error between FY90 and 98 were analyzed for role of weather. In addition to determining the overall role of weather, various aspects of the mishaps such as aircraft category, type of mishaps, type of weather and flight phase were investigated.

A third thesis effort is underway. LT Todd Barnhill is working with Professor C. Wash and FNMOC advisor Mr. Dave Huff to modernize the FNMOC support and products used in ship routing and ship forecasting. This thesis will be completed in FY2002.

PROJECT SUMMARIES

THESIS DIRECTED:

Barto, K., "Improvements to METOC Analysis and Forecast Visualizations," Masters Thesis, Naval Postgraduate School, September 2000.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Operational Mission, Marine Meteorology, FNMOC Support

TAMS-RT VERIFICATION AND EVALUATION

Carlyle H. Wash, Professor

Department of Meteorology

Sponsor: Space and Naval Warfare Systems Command (PMW-185)

OBJECTIVE: The technical objective of this project is to verify and evaluate NPMOC San Diego TAMS-RT and other COAMPS mesoscale forecasts using all available local and mesoscale data.

SUMMARY: This project has established a cassette tape archive of all TAMS-RT San Diego forecasts. In addition one thesis was completed. LCDR Greg Schmeiser, USN investigated the ability of COAMPS to forecast the major East Coast cyclone of 24-26 January 2000. This storm was of particular interest due to the poor performance of many numerical and human forecasts. LCDR Schmeiser found COAMPS did provide a very accurate storm track and forecast of intensity. However, it failed, as did many other models, in resolving the associated heavy snow and precipitation bands. Some experimental forecasts uses the new data assimilation system (NAVDAS) did have positive impacts on the forecasts.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation

KEYWORDS: Cloud Forecasting, Precipitation Forecasting, COAMPS, Mesoscale Modeling and Forecasting

SUPPORT FOR METOC SABBATICAL VISITING ALL CNMOC

REGIONAL CENTERS AND FACILITIES

Carlyle H. Wash, Professor

Department of Meteorology

Sponsors: Office of Naval Research and
Naval Meteorology and Oceanography Command

OBJECTIVE: During FY00, Professors Wash and Rosenfeld of the Naval Postgraduate School's Meteorology and Oceanography Departments, respectively, made extended visits to each of the Naval Meteorology and Oceanography Command's regional centers and facilities for the purposes of providing training, evaluating the use of METOC data, models, and tactical decision aids, and gathering information to aid in the improvement of the METOC curricula at NPS. A Technical Report was completed giving a synopsis of their findings integrated over all of their visits.

SUMMARY: From the sabbatical activity, three major roles for METOC regional centers and facilities are identified: i) to be a source of local METOC knowledge and expertise for their area of responsibility, including familiarity with mesoscale circulations and all reliable sources of real-time data and model output; ii) to provide operational support to the fleet, including customized fused products and littoral oceanography products; and iii) to provide training for METOC personnel in regional-specific meteorology and oceanography, and continuing advanced technical training. A major finding is that technical education and training is inadequate to allow METOC personnel to take maximum advantage of the full range of data, models, and tactical decision aids available to them. Weaknesses in the quality-control and verification of METOC analysis and forecast products are also identified. A number of innovative practices at individual commands are recommended for adoption throughout the claimancy.

PROJECT SUMMARIES

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Meteorological Analysis, Numerical Weather Prediction, Numerical Ocean Prediction, Mesoscale Analysis, Modeling and Forecasting

BOUNDARY LAYER EFFECTS ON MESOSCALE PHENOMENA

R. T. Williams, Professor
Department of Meteorology
Sponsor: Office of Naval Research

OBJECTIVE: To improve the simulations of mesoscale phenomena over topography with boundary layer effects.

SUMMARY: It was found by numerical investigation that boundary layer mixing has a strong effect on cold fronts moving over large-scale topography. In particular the fronts become stronger as they moved up the mountain slope, while the opposite happened when there was no boundary layer. Also unbalanced frontogenesis was examined by considering an initial temperature disturbance with no initial wind. The calculations were carried out with zero potential vorticity that corresponds to zero static stability in the initial state. A frontal discontinuity was obtained when the Rossby number was above a critical value. Otherwise a modified inertial oscillation was obtained.

PUBLICATIONS:

Peng, M.S., Powell, J.H., Williams, R.T., and Jeng, B.F., "Boundary Layer Effects on Fronts Over Topography," *Journal of Atmospheric Sciences*, accepted for publication.

Blumen, W. and Williams, R.T., "Unbalanced Frontogenesis: Part I. Zero Potential Vorticity," *Journal of Atmospheric Sciences*, accepted for publication.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Numerical Models, Topographic Effects, Boundary Layer

**DEPARTMENT OF
METEOROLOGY**

**2000
Faculty Publications
and Presentations**

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DEPARTMENT OF METEOROLOGY

Thesis Abstracts

THESIS ABSTRACTS

IMPROVEMENT OF METOC ANALYSIS AND FORECAST VISUALIZATIONS

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Master of Science in Meteorology and Physical Oceanography-September 2000

Advisor: Carlyle H. Wash, Department of Meteorology

Second Reader: Kenneth L. Davidson, Department of Meteorology

Current METOC weather visualization tools do not allow warfighters, forecasters, and researchers to analyze and co-display environmental data over realistic topographic and bathymetric backgrounds. In this thesis the Joint METOC Global Image Interface is developed and provides decisionmakers and geoscientists with an intuitive tool for interactively viewing, overlaying, and outputting the full suite of FNMOC distributed environmental data over realistic and accurate terrain, coastlines, hydrography, and locally obtained imagery. Full integration into the Joint METOC Viewer ensures minimal training time for operational use and geodata distribution is accomplished on the program distribution CD or over the web. The evolution of traditional METOC visualization, and the characteristics of the geodatabases are discussed and recommendations for further work in this area are presented. New capabilities are illustrated using real world examples drawn from diverse application areas.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Modeling and Simulation, Computing and Software

KEYWORDS: Visualization, Meteorology and Oceanography, METOC, Forecasting, Analysis

EVALUATION OF DYNAMICAL TRACK PREDICTIONS FOR TROPICAL CYCLONES IN THE ATLANTIC DURING 1997-98

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Lester E. Carr, III, Department of Meteorology

Carr and Elsberry (1999; NPS Technical Report) have described eight conceptual models that explain most cases of large (> 300 n mi at 72 h) western North Pacific tropical cyclone (TC) track errors by the Navy Operational Global Atmospheric Prediction System (NOGAPS) and the Geophysical Fluid Dynamics Lab (Navy version - GFDN) models. This study is for TCs in the Atlantic basin and includes the European Centre for Medium-range Weather Forecasting (ECMWF) and the United Kingdom Meteorological Office global models, whereas the GFDL model is eliminated. A detailed examination is made of large (> 250 n mi at 72 h) errors made by the three dynamical models for two seasons of Atlantic TC tracks (1997-98). The percentages of > 250 n mi 72-h errors for the NOGAPS, UKMO, and ECMWF models were 23%, 26%, and 19%, respectively. The same error mechanisms found to apply in other basins also affect the dynamical models in the Atlantic. The NOGAPS and UKMO models have a tendency to over-represent TCs and other circulations, which leads to a cyclonic rotation, or even merger, via the Excessive Direct Cyclone Interaction (E-DCI) process, just as was found in the western North Pacific. The primary ECMWF error source was Excessive Midlatitude CycloGenesis (MCG).

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: Tropical Cyclone Track Forecasting, Tropical Cyclone Motion

**ERROR ANALYSIS OF REAL-TIME REMOTELY SENSED MICROWAVE SEA-ICE MOTIONS
IN THE WESTERN ARCTIC OCEAN**

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An algorithm used to composite SSM/I 85.5 GHz imagery and derive sea ice motion was adapted for operational testing at Fleet Numerical Meteorology and Oceanography Command (FNMOC). A feature tracking technique was applied to a 6-month period, with data provided by FNMOC and the Naval Research Laboratory (NRL). Ice motions are detectable using the SSM/I motion algorithm, and fields of SSM/I motion vectors are qualitatively consistent with coincident fields of in situ buoy motion vectors. Accuracy of the SSM/I motion vectors relative to buoy motion vectors increase significantly with buoy speed. No correlation between SSM/I and buoy motion vectors is observed for speeds below 3 cm/s and correlation increases significantly above 5 cm/s. The results are very sensitive to compositing techniques used to combine SSM/I passes into a single sea ice representation. FNMOC data was composited using a "drop-in-the-bucket" technique while NRL data was composited by a bi-linear interpolation technique. Significantly poorer results were found with FNMOC composited data.

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: Microwave, Remote Sensing, Arctic Sea Ice, Sea Ice Motion

**EL NIÑO AND LA NIÑA EFFECTS ON TROPICAL CYCLONES:
THE MECHANISMS**

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The effects that El Niño and La Niña events exert on western North Pacific tropical cyclones, and the physical mechanisms involved were examined using best track data from the Joint Typhoon Warning Center and NCEP reanalysis data. During El Niño and La Niña events, equatorial heating anomalies induce anomalous tropical and extratropical atmospheric wave trains which alter circulation, vertical shear, and steering flow.

The shear changes cause tropical cyclones to form farther south and east (north and west) than normal during El Niño (La Niña) events. These formation differences lead to longer (shorter) tracks and stronger (weaker) tropical cyclones during El Niño (La Niña) events. Late in the tropical cyclone season, the anomalous extratropical waves alter the subtropical ridge and steering flow to favor recurving (straight running) tropical cyclones during El Niño (La Niña). These track differences lead to a much higher number of landfalling tropical cyclones in southeast Asia during La Niña events.

A preliminary study of the North Atlantic shows that there are more, and stronger, tropical cyclones during La Niña than El Niño. This is the result of extratropical Rossby wave trains that originate in the east Asia and extend into the North Atlantic. There they alter the vertical shear, so that La Niña favor more formations in the tropical Atlantic, where other conditions are favorable for the development of strong tropical cyclones.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Environmental Quality, Sensors, Modeling and Simulation, Other (Meteorology, Oceanography)

KEYWORDS: El Niño, La Niña, Tropical Cyclones, Hurricanes, Typhoons, Climate, Pacific, Atlantic

TURBULENCE PROFILES AND OUTER LENGTH SCALE DETERMINATION IN THE ATMOSPHERE USING BALLOONS

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Turbulence in the atmosphere drives the formation of temperature inhomogeneities that scatter and diffract propagating electromagnetic waves, adversely affecting laser weapons and high-resolution optical systems. Military operations require reliable turbulence profiles for the development and validation of turbulence prediction models.

This research investigated the false turbulence contribution caused by well-known temperature steps in the vertical profile of the atmosphere, especially in the stratosphere. The homogeneity and isotropy requirements of structure functions were used to develop a technique to remove the false contribution to the temperature structure constant, C_τ^2 .

Both 1.54 cm and 5.82 m vertical resolution profiles with 0.001 to 0.01 K temperature resolution were collected from a balloon flight. Steps of 0.1 to 1 K in the vertical temperature profile produce abrupt changes in the mean temperature that obscure the measurement of the actual turbulent fluctuations. Removing these anomalies exposed the underlying C_τ^2 distribution. Application of the new technique for several sampling intervals revealed a Kolmogorov inertial subrange extending from ~25 cm to ~10 m. The potential of this technique to compute the isoplanatic angle, θ_0 , coherence length, r_0 , and Greenwood frequency, f_g , reliably by using inexpensive balloons should benefit airborne and space-based laser programs.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Directed Energy Weapons, Modeling and Simulation

KEYWORDS: Adaptive, Atmosphere, Laser, Optics, Propagation, Turbulence

A STUDY ON THE TIMING OF THE SOUTHWEST MONSOON ONSET IN THE SOUTH CHINA SEA

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The boreal summer in the South China Sea is preceded by a spring to summer transition period that coincides with the end of the dry season and start of the rainy season throughout Southeast Asia. The rainy season is identified with the arrival of the Southwest Monsoon. The monsoon onset in the northern portion of the South China Sea normally occurs during May of each year but can range from early May to early June. This work studied the differences of the large scale flow for different timing categories of onset, and if differences could be noted during onset with the presence of tropical cyclones. NCEP/NCAR reanalyses data and NOAA AVHRR GPI data from OLR fields were used for May and June for the years 1979 – 1999. Timing of onset appears to be determined by the arrival of the Mei-Yu front. When tropical cyclones are present, a vortex tends to occur in the Bay of Bengal.

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: Monsoon Onset, Southwest Monsoon

**LARGE EDDY SIMULATION OF INTERACTIONS BETWEEN FREE CONVECTION, WIND
DRIVEN CURRENTS, AND BAROCLINICITY IN THE LABRADOR SEA
DEEP MIXED LAYERS****Denise M. Kruse-Lieutenant, United States Navy****B.S., George Washington University, 1989****Master of Science in Meteorology and Physical Oceanography-June 2000****Advisors: Peter S. Guest, Department of Meteorology****Ramsey Harcourt, Department of Oceanography**

Understanding the dynamics of deep convection leading to the formation of deep water is important not only for studying the small-scale generation regions, but also for studying the global-scale thermohaline circulation. Large Eddy Simulation (LES) is used to model deep convection with an imposed mean horizontal density gradient of two different strengths and wind forcing from various directions, with strong surface cooling representative of the Labrador Sea. Results from these different cases are compared and analyzed to understand the effects of horizontal density gradients and wind direction on turbulence statistics for deep convection. Both the strength of horizontal density gradients and wind direction relative to the gradient affect mixed layer scalar variances, turbulent vertical fluxes, Vertical Turbulent Kinetic Energy (VTKE), and stability during deep convection.

Wind direction dominates over gradient strength in determining vertical flux magnitude with larger variation in strong gradient cases. Levels of VTKE are more dependent on gradient strength, with weaker gradients producing higher values of VTKE than stronger gradients regardless of wind direction. Wind direction does alter VTKE levels in the same manner as it alters vertical flux levels. The presence of a horizontal gradient is a stabilizing factor in areas of strong surface cooling.

DoD KEY TECHNOLOGY AREA: Other (Meteorology and Oceanography)**KEYWORDS:** Large Eddy Simulation, Deep Convection, Labrador Sea, Baroclinicity**UNDERSTANDING MESOSCALE ERROR GROWTH AND PREDICTABILITY****Michael A. Kuypers-Lieutenant, United States Navy****B.S., United States Naval Academy, 1991****Master of Science in Meteorology and Physical Oceanography-June 2000****Advisor: Wendell A. Nuss, Department of Meteorology****Second Reader: Douglas K. Miller, Department of Meteorology**

Technological advances have made atmospheric mesoscale modeling at very fine resolutions readily available to a great number of organizations. Though initial operational results show some skill with respect to synoptic scale forecasts, many of the problems associated with mesoscale error growth and predictability have been ignored. Understanding mesoscale error is critical to accurately interpreting mesoscale model results and output from tactical decision aids (TDAs).

This study examines mesoscale error growth and predictability through controlled numerical model experiments. A known "true" atmosphere is created through the use of the US Navy's Coupled Oceanographic/Atmospheric Mesoscale Prediction System (COAMPS). Virtual observations are randomly sampled from this atmosphere to provide data for ingest into forecasts using the NCAR/Penn State MM5 mesoscale model. Forecast results for ten cases are compared against the "true" atmospheric solution and error statistics are calculated for wind speed and geopotential height fields. Results show how error growth and predictability are affected by different variables such as boundary conditions, weather regime, sample size and sample distribution. A scale separation of error is also performed in order to assess the impact of synoptic scale error on mesoscale error.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Modeling and Simulation**KEYWORDS:** Mesoscale Modeling, Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS), Error Growth, Predictability

ESTIMATION OF STRATOCUMULUS-TOPPED BOUNDARY LAYER DEPTH USING SEA SURFACE AND REMOTELY SENSED CLOUD-TOP TEMPERATURES

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Master of Science in Meteorology and Physical Oceanography

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Carlyle H. Wash, Department of Meteorology

The depth of the marine atmospheric boundary layer (MABL) is an important parameter for both scientific and operational meteorological applications. The depth of the marine boundary layer has a significant influence on the atmospheric dynamics in the coastal zone. Knowledge of the depth of stratocumulus-topped boundary layers (STBLs) will enable coastal operations to more accurately anticipate weather, and electromagnetic propagation conditions. This study develops a satellite remote sensing technique for determining the height of MABLs topped with stratocumulus clouds.

Validation of the technique using coastal rawinsonde dataset from the Monterey Area Ship Track (MAST) experiment revealed that an assumption of 41% cloud with a moist lapse rate equal to $-7.0^{\circ}\text{C}/\text{km}$ had the best overall fit to the data. However, for shallow boundary layers with depths below 400m the most accurate assumption was 75% cloud with a moist lapse rate equal to $-6.5^{\circ}\text{C}/\text{km}$. The application of this technique to sounding data returned an overall BL depth accuracy of 50m while the satellite application returned an overall accuracy of 65m. A sensitivity analysis of both surface and cloud-top temperature revealed that a $1/2^{\circ}\text{C}$ change in either temperature resulted in an error of 60-70m in boundary layer depth.

DoD KEY TECHNOLOGY AREA: Other (Meteorology, Oceanography)

KEYWORDS: Boundary Layer Depth, Remote Sensing, Stratocumulus, AVHRR

OPTIMIZATION OF MAS AND MODIS POLAR OCEAN CLOUD MASK

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Master of Science in Meteorology and Oceanography-June 2000

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With the reduction of funding for sea ice reconnaissance flights, the National/Naval Ice Center needs to capitalize on the improvements in satellite technology. Imaging sensors such as AVHRR, DMSP/OLS, SSM/I and RADARSAT are used to detect the presence of sea ice, but with the exception of SSM/I and RADARSAT, clouds are a major obstacle to viewing the surface. With NASA's development of the Moderate-resolution Imaging Spectroradiometer (MODIS) and MODIS Airborne Simulator (MAS), there is finally a sensor capable of using multi-spectral techniques to detect the presence of clouds.

A group at the Space Science and Engineering Center (SSEC), University of Wisconsin - Madison lead by Dr. Steve Ackerman has developed a cloud mask for MAS/MODIS. The technique determines a level of confidence that a given pixel is clear based on a series of multi-spectral tests. By combining the confidence level from all tests, it is possible to detect the presence of clouds at different altitudes in the atmosphere. Threshold optimizations are described in this thesis for the $T_B(11\mu\text{m})$ and $T_B(3.9\mu\text{m}) - T_B(11\mu\text{m})$ tests from Ackerman et al. (1997). In addition, the $T_B(11\mu\text{m}) - T_B(12\mu\text{m})$ test is removed. These modifications are based on daytime analysis of several MAS cases and a limited number of MODIS cases.

Subjective analysis shows the modifications greatly improve the detection of clouds over cold polar oceans where sub-pixel ice may be present or water temperatures might falsely indicate clouds. The number of *Cloudy* pixels (≥ 0.66 clear confidence level) for a given scene was increased 12.1% on average for MAS cases. The NPS cloud mask also classified two times more *Probably Clear* and *Undecided* pixels than the original mask due to greater sensitivity to thin, small clouds.

THESIS ABSTRACTS

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Sensors, Other (Remote Sensing)

KEYWORDS: Moderate Resolution Imaging Spectroradiometer (MODIS), MODIS Airborne Simulator, Terra Satellite, Cloud Mask, Sea Ice

FORECASTING MESOSCALE WINDS ON COMPLEX TERRAIN USING A SIMPLE DIAGNOSTIC MODEL

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The use of mesoscale models to provide an accurate representation of what the atmosphere is likely to do in the near future is one of the tools forecasters utilize to predict atmospheric variables. Because of the large amount of time and computer resources necessary to provide detailed forecasts on the mesoscale, this study looked at forecasting winds utilizing a simple diagnostic model and compared its results to a full physics model. Winds from the Fifth Generation Mesoscale Model (MM5), were run at fairly coarse grid spacings of 81, 27, and 9 kilometers and at a finer grid spacing of three kilometers. The MM5 9 kilometer results were input into the Winds On Critical Streamline Surfaces (WOCSS) model, which is a scaled down physics model designed to adjust winds to fine scale topography. A comparison of how the WOCSS model winds compared against each of the MM5 grid spacings was evaluated for an event during the period 4-7 August 1997 in the SOCAL bight region to determine if the results of the scaled down physics model were comparable to the full physics model. This experiment showed encouraging results for forecasting fine scale winds on complex topography using the simple diagnostic model.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Environmental Quality, Modeling and Simulation

KEYWORDS: Mesoscale Modeling, Wind Forecasting, Wind Simulation

COMPARISON OF TAMS/RT SURFACE WIND, TEMPERATURE, AND PRESSURE FIELDS WITH SURFACE OBSERVATIONS AND MODEL ANALYSES IN THE SOCAL AREA

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M.S., University of Puerto Rico, 1986

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Second Reader: Douglas K. Miller, Department of Meteorology

The Tactical Atmospheric Modeling System/Real Time (TAMS/RT) combines the high-resolution Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) and the Tactical Environmental Data Server (TEDS).

In this study, TAMS/RT sea level pressure, 10 meter (m) winds and 2 m air temperature fields generated at the Naval Pacific Meteorology Oceanography Center (NPMOC) in San Diego are evaluated. Outer nest (45 and 54 kms) sea level pressure 12 and 24-hour forecasts are qualitatively compared with model analyses. Then surface observations with inner nest (5 and 6 kms) model wind (u and v) and temperature forecast fields (00, 06, 12, 18, and 24-hour) are quantitatively compared.

Contrary to expectations, no error growth through the forecast cycle and relatively high error in the initial analysis for all variables was found. When examined by 0000Z and 1200Z model runs, a repetitive pattern related to the diurnal cycle which impact use by a forecaster was found. Day to day error was linked to the diurnal pattern and larger magnitude error to cold starts, background fields, and data assimilation problems. High variability among observed and model values was observed but still found various model trends that require further evaluation.

THESIS ABSTRACTS

DoD KEY TECHNOLOGY AREAS: Environmental Quality, Modeling and Simulation, Other (Meteorology)

KEYWORDS: Mesoscale Modeling, Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS), Tactical Atmospheric Modeling System/Real-Time (TAMS-RT), Data Assimilation, Model Verification, Predictability

AUTOMATED METEOROLOGICAL AND OCEANOGRAPHIC DATA COLLECTION AND DISTRIBUTION IN SUPPORT OF C4I, WEAPONS, AND REMOTE SENSING SYSTEMS

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On-scene characterization of the battlespace environment is critical toward providing the warfighter with an effective understanding of the environment and its impact on weapon systems and sensors and requires the rapid acquisition and dissemination of on-scene meteorological and oceanographic (METOC) measurements. The current practice of manually observing and recording METOC data is labor intensive, outdated, and no longer capable of satisfying the requirements for higher temporal and spatial observations.

This study reviews the current methodology to characterize the battlespace environment, summarizes relevant Navy needs, and describes the results of integrating a prototype small combatant integrated METOC system (SCIMS) developed by the Naval Postgraduate School, with a prototype data processing and distribution system (Weather Viewer) developed by SPAWARSYSCEN San Diego.

At-sea demonstration included the acquisition, encoding, transmission and retrieval of real-time observations to/from shore based METOC data servers at Fleet Numerical Meteorology and Oceanography Center via commercial telephone access to the Internet. The demonstration further served as the basis for development of a PC based prototype Shipboard METOC Archive and Reports system called SMART Log.

The study concludes with particular recommendations for updating and improving the system of environmental data collection, processing, utilization, and archival.

DOD KEY TECHNOLOGY AREAS: Air Vehicles, Battlespace Environments, Command, Control and Communications, Computing and Software, Electronic Warfare, Environmental Quality, Sensors, Surface/Under Surface Vehicles - Ships and Watercraft, Modeling and Simulation

KEYWORDS: Internet, Metcast, Meteorology, METOC, Moriah, Oceanography, SCIMS, Seawasp

EVALUATION STUDY OF THE TACTICAL ATMOSPHERIC MODELING SYSTEM/REAL-TIME (TAMS-RT) AT NPMOC SAN DIEGO

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Second Reader: Wendell A. Nuss, Department of Meteorology

The U.S. Navy is aggressively pursuing mesoscale atmospheric modeling. The Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) has been developed by the Naval Research Lab in Monterey, California to meet this task. A forecast system employing COAMPS, called the Tactical Atmospheric Mesoscale System- Real Time (TAMS-RT), is currently being field tested at two of the Navy's major regional weather facilities in Manama, Bahrain and San Diego, California. Mesoscale modeling is a complex process that requires detailed knowledge of mesoscale forcing and responses, as well as a capable data display system to make the best use of this new capability. While the challenge of interpretation of forecasts on the mesoscale has increased, the time available for producing forecasts has, if

THESIS ABSTRACTS

anything, decreased. Optimal methods of evaluation and display are needed that enable a forecaster to rapidly, yet skillfully complete this process. This thesis illustrates analysis techniques to aid in rapidly evaluating the utility of any given mesoscale forecast and proposes optimal methods for 3-D visualization and interpretation of various weather parameters. Using these techniques and methods, TAMS-RT performance is then evaluated for critical mesoscale weather phenomena as defined by NPMOC San Diego, including the mesoscale weather effects associated with frontal passages and the Catalina Eddy.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Environmental Quality, Modeling and Simulation

KEYWORDS: Mesoscale Modeling, Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS), Tactical Atmospheric Modeling System/Real-Time (TAMS-RT), Catalina Eddies

PERFORMANCE EVALUATION OF INTEGRATED METOC MEASUREMENT SYSTEM SUPPORTING NAVAL OPERATIONS

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MORIAH is a shipboard METOC measurement system planned for installation on 72 AEGIS ships. A prototype MORIAH system (SEAWASP) was deployed for an 8 month period on two carrier groups: USS Anzio and USS Cape St. George. The SEAWASP accuracy and reliability were evaluated in the context of the MORIAH Operational Requirements Document (ORD) and AEGIS operating requirements. Measures of accuracy were RMS differences between simultaneous ship measurements when their separation was less than 10 and 5 kilometers. Measures of reliability were based on the number of mast average records possible in a period, recorded in a period, and validated in a period. For ORD accuracy, only air temperature and relative humidity met ORD Threshold requirements. For ORD reliability, Anzio's system did not meet requirements because a power surge caused failure of several ship systems including SEAWASP. Applying AEGIS accuracy requirements, only relative humidity passed. This result caused ship evaporation duct heights to agree during unstable and neutral conditions but significantly diverge in low wind / humidity and stable conditions. SEAWASP did not provide sufficient reliability for continuous propagation assessments. Validated data for both ships were less than 50%. Significant gains (25%) in reliability performance were shown using modified selection criteria.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Electronics Warfare, Sensors

KEYWORDS: AEGIS, Evaporation Duct, LKB, MORIAH, SEAWASP, USS Anzio, USS Cape St. George

AMBIENT NOISE CHARACTERISTICS DURING THE SHEBA EXPERIMENT

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The ambient noise data recorded by two free-drifting buoys during the 1997-98 SHEBA experiment presented a unique opportunity to gauge the noise field of the Arctic Ocean in a unique and changing environment. The two buoys drifted in unison for 12 months, providing an hourly ambient noise data set between 50 and 1000 Hz. The drift pattern was divided into five legs in response to the season or major changes in the direction of ice flow. The two buoys exhibited similar median spectra for all frequencies.

When examined on a seasonal basis, summer low frequency (< 200 Hz) noise levels were much closer to winter noise levels than past studies. This was mainly due to the low number of storms during the winter of 1997-98, which resulted in lower winter median noise levels. When compared with previous ambient noise studies in the Beaufort Sea, the SHEBA noise data were consistent with the concept that noise levels decrease (especially in summer) during the years when cyclonic atmospheric circulation dominates the west Arctic. Cross correlation analysis indicated a strong association of wind speed and wind stress to ambient noise. Locally measured wind stress (as opposed to that computed using the geostrophic wind) did not substantially improve the correlation with ambient noise. Two tools to conceptualize the Arctic noise field were employed during the SHEBA experiment: the use of RADARSAT with RGPS and the PIPS computation of energy dissipation rate. By comparing the output from these two systems with the ambient noise record, their effectiveness and usefulness as input to an Arctic ambient noise model could be determined. Several notable events in the winter and summer noise record were examined utilizing RGPS and PIPS. The event analysis confirmed the fact that distant noise sources can have an effect on a local noise field. RGPS and PIPS were not useful in the summer due to the open nature of the icepack.

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: Ambient Noise, SHEBA Experiment

A COMPOSITE STUDY OF THE MADDEN-JULIAN OSCILLATION (MJO) AND NORTHEASTERLY COLD-SURGES DURING THE NORTHERN WINTER MONSOON

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Master of Science in Meteorology and Physical Oceanography-March 2000

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During the northern winter monsoon, the Madden-Julian Oscillation (MJO) and northeasterly cold-surges are active over the eastern Indian Ocean and western Pacific. The MJO consists of an active (wet) phase and inactive (dry) phase and varies over global spatial and intraseasonal time scales. Interactions between the MJO and northeasterly cold-surges, which vary over regional space and synoptic time scales, are examined. The interactions are examined between 1979-1998 using winds at 1000 hPa and a representation of convection during the northern winter monsoon. To identify interactions, the active and inactive phases of the MJO are divided into early or late phases (based on MJO duration). Examination of composite maps based on cold-surges defined to occur during each phase of the MJO revealed that the phase of the MJO acts to either enhance or weaken a cold-surge that may have been forced by the mid-latitudes. When MJO convection is located over the South China Sea, the surge intensifies. The favorable convection pattern dominates the unfavorable pressure-wind pattern of the MJO. When the MJO dry-phase is over the South China Sea, mid-latitude forcing appears to interact favorably with the pressure-wind pattern of the MJO to dominate the unfavorable MJO convection pattern.

DoD KEY TECHNOLOGY AREA: Other (Monsoon Meteorology)

KEYWORDS: Northern Winter Monsoon, Madden-Julian Oscillation, Northeasterly Cold-Surges

**SUPPRESSION OF MARINE STRATOCUMULUS CLOUDS DUE TO REDUCED CLOUD
CONDENSATION NUCLEI**

**Neil Tyler Smith-Lieutenant, United States Navy
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Master of Science in Meteorology and Physical Oceanography-September 2000

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Second Reader: Qing Wang, Department of Meteorology

Cloud researchers have documented a variety of processes at work in the formation and dissipation of clouds in the marine boundary layer (MBL). Cloud rifts occasionally mark a distinct exception to the continuity and broad coverage more commonly observed with these clouds. A possible explanation for the presence of large features of broken cloudiness embedded in stratocumulus is the removal of CCN by nucleation scavenging and drizzle.

A cloud rift feature embedded in marine stratocumulus was observed in satellite imagery on July 16, 1999. A CIRPAS Twin Otter aircraft flew repeated crossings of the rift boundary while completing a comprehensive survey of the area. A comparison of microphysics and thermodynamics on opposite sides of the rift boundary indicate that these rifts form where low aerosol concentrations enhance drizzle production. Marine boundary layer aerosol concentrations in the rift were only 1/6 that observed below the background stratocumulus. Cloud droplets in rift clouds were 3-5 microns larger than droplets in stratocumulus and exhibited a broader size distribution. Drizzle observations were strongly correlated with the rift and calculations support a drizzle hypothesis for rift formation and maintenance. Aerosol losses can be accounted for in drizzle droplets and the disruption of the cloud layer evolves in a manner described by Ackerman (1993).

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: Marine Clouds, Precipitation, Aerosol, Marine Atmospheric Boundary Layer, Environmental Effects

CONVECTIVE ACTIVITIES WITHIN THE STRATOCUMULUS-TOPPED BOUNDARY LAYER

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This study utilizes aircraft measurements obtained off the California coast to analyze the geometric, thermodynamic, and microphysical characteristics of convective updrafts and downdrafts in the stratocumulus-topped boundary layer (BL). The vertical structure of thermodynamic and microphysical properties is consistent. The difference in peak droplet concentration between updrafts, downdrafts, and the defined environment increases near the cloud top. We observe larger mean droplet diameters in downdrafts near the cloud top, as the number of small droplets in cloud top downdrafts appears to decrease. The horizontal variability seen in the cloud droplet spectra and microphysics properties is likely due to aerosol activation and growth in updrafts, cloud top entrainment, and penetrating cumulus. We compute the mass flux, ω^* , using a mass flux parameterization. Several measured variables produce consistent results and agree with mass flux calculations from other stratocumulus datasets.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Environmental Quality

KEYWORDS: Convective Events, Cloud Microphysics, Stratocumulus-Topped Boundary Layer, FIRE

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